FOCUSED APPROACH TO THE GENERAL FLOW SHOP SCHEDULING WITH TRADINESS CRITERIA

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CERTIFICATE

This is to certify that the present work on **Focused Approach To The General Flow Shop Scheduling With Tardiness Criteria**, by S. N. KASTURI RANGAN has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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CONTENTS

SYNOPSIS

Scheduling procedures using focused approach to the general flow shop scheduling problems with weighted tardiness criteria are developed in this work. Focused approah involves identification of the bottleneck machine and concentrating on the information on the bottleneck machine to make effective scheduling decisions. For using the focused approach first the bottleneck is to be identified. Three rules for identification of bottleneck are developed for this purpose. Two rules to use the information on the bottleneck machine are developed. Four scheduling heuristic using the above rules are developed and compared with two other scheduling methods. The focussed approach performed far better than those other scheduling methods. An interactive computer system is developed to enable the heuristics meet the requirements of practical scheduling applications.

CHAPTER 1

INTRODUCTION

The main approaches to production scheduling problems may be broadly classified into (i) Heuristic procedures or decision rules and (ii) Optimum seeking procedures.

Decision rules have limited computational requirement and more important have predictable computational requirements for problems of given size. They are useful in situations where optimum seeking procedures are impractical because of either the computational requirement they call for or difficulty in designing a solution procedure. Though decision rules do not guarantee optimality they strive to achieve local optimal solutions. However it is difficult to judge the effectiveness of decision rules. Most decision rules are evaluated by computer simulation studies under certain assumptions for either the problem definition or the parameters involved.

Considerable research effort has been directed towards the solution of the combinatorial optimization problem associated with the scheduling of n jobs , m machines in a shop where the flow of jobs to machines is unidirectional. This problem was first formulated by Johnson[16] as a n-job, 2-machine scheduling problem with the objective of minimising the total time to complete all the jobs. Subsequent research publications have shown that the solution to the general flow shop scheduling problem can be obtained with exhaustive enumeration. The computational requirments associated with the factorial nature of

the possible schedules, however, prohibits a practical soloution of the moderately large sized problems [13]. Because of these difficulties it appears that the only suitable means of solving a flow shop scheduling problem of any size are the heuristic procedures, which, while not guarantying optimal solutions, do reliably produce satisfactory solutions with a resonably small amount of computational effort.

The problem considered is one which emulates a general flow shop which produce products from distinctly different groups on the same machines and in which the flow of jobs to machines is unidirectional. Each product group had a different pattern of processing times on the machines and in particular the largest processing times for each product group may be in different machines. The assumptions made are:

(1) all jobs are available at time t = Ø

(2) all the machines are free at time t = Ø

(3) all the jobs pass through the machines in the same sequence

(4) all the machines have the same job sequence loading

The above assumptions make the problem closely approximate a general flow shop. Though the first two assumptions can be considered restrictive, they are in general acceptable. Each job j has a duedate Dj, a tardiness cost or job weight Wj. The objective is to minimize the weighted tardiness of jobs. In a recent publication Peng Si Ow [26] has used an entirely new approach to the proportionate flow shop scheduling

problem with the objective of minimising weighted tardiness of jobs. The approach which Peng Si Ow calls the Focused approach, uses a characteristic of the flow shop scheduling problem which is obvious and yet neglected by past researchers in scheduling. In focused scheduling the importance of bottleneck machine and the effectiveness of the approach that focuses on the information on the bottleneck machine has been stressed. The results of the tests conducted by Peng Si Ow indicated that the scheduling decisions can be significantly improved by explicitly considering the effects on the bottleneck machine. The work of Peng Si Ow is mainly on a subset of the general flow shop sheduling problems called the proportionate flow shops where the bottleneck machine is stationary and can be identified in advance.

The main effort in this work is directed to adopt the focused approach to the general flow shop problems. The concept of bottleneck in such situations has to be different from that in proportionate flow shop. In a general flow shop the bottleneck machine may be dynamic and may depend on the schedule being built up. The identification of the bottleneck machine is important as the focussed approach uses the knowledge of the bottleneck in the solution to the scheduling problems. Three rules are developed for identifying the likely bottleneck machine in general flow shop problems. The development of the bottleneck identification rules are discussed in detail. Two job selection rules are used for selection of jobs based on the bottleneck identified. The job selection rules idle time rule and modified idle time rules are described. Effort was made to study the effects of two

parameters, resource constant and lookahead parameter, which are used in the job selection rules under different scenarios of tardiness factor and duedate distribution. Four solution procedures developed using the above bottleneck identification and job selection rules are presented. These solution procedures were compared with two dispatch methods EDD and WSPT under different scenarios of tardiness factor and due date distribution.

The results of the study indicate that the focused approach does improve the scheduling decisions. Scheduling decisions based on the heuristics which use the focused approach are more effective than the traditional approaches.

Interactive Scheduling As An Approach To Practical Scheduling

A lot of research work has been done in the multi-machine scheduling but very few have found practical applications. Still the simplistic rules like EDD, WSPT and FCFS are very popular and find wide acceptance and application. One reason, why they are given preference over other better performance heuristics, is that they are simple to understand and apply in practical situations. The lack of effort on the part of the researchers to take into consideration practical aspects of scheduling being the reason. This situation arose mainly because of the diverse and sometimes totally conflicting objectives and conditions attached to diferent scheduling applications and the complexity that each such practical consideration brings into the problem, making it more and more difficult to design the solution

rocedure to the problem. Gupta [10]-[13] discusses several spects of the FSS problem which seem to have been neglected in the research efforts to find a practical solution. Field research conducted in various industries by Beswick & Loceyer [4] suggests that any useful scheduling system must :

(1) Produce a feasible schedule rapidly

(2) Accomodate changes rapidly

(3) Perform priority or partial priority scheduling

(4) Perform duedate scheduling

(5) Handle backpassing technological routes

(6) Handle parallel processing work centres

(7) Be intelligible to administrators and operators of the system

Scheduling procedures in multi-machine shops can be broadly classified into 'Centralised' and 'De-centralised' procedures. This classification is based on whether the shop schedule can be built by each machine operator independently or the entire schedule must be centrally drawn up and the schedule instruction disseminated to the machine operators. For example, dispatch methods are decentralised procedures because the scheduling may be done independently by each machine operator by applying some dispatch rule, while the more sophisticated procedures are centralised procedures. The advantage of decentralised approach is that the scheduling decisions can be made with the most up-to-date information on the state of the machine being scheduled. The decision on one machine may be in conflict with the decision at some other machine. The

centralised approach is more systematic eliminating the conflicting decisions at different machines. But the response to the environmental chenges in the case of the centralised approach, will be slower, which has to be overcome with the currently available technologies like real time scheduling.

Scheduling, an attempt to plan the use of resources, is inevitably in conflict with the ability to respond to change. The converse is equally true - the greater the freedom to change the less efficient the use of resources. A study on the practical aspects of scheduling by Bestwick and Loceyer [4] revealed that the continual changes of priorities which occur at the progress meetings often result in the destruction of effective scheduling. A serious organisational dilemma is thus created: if performance objectives are to be achieved then the organisation must behave in a disciplined way or must be prepared to accept substancial under utilisation of resources. Since the changes in priorities are in most cases unavoidable, continuous updation of the schedule, always keeping in view the main objectives, is needed. Scheduling therefore cannot be carried out in isolation.

Whatever solution method is proposed and however it is presented, its execution will ultimately rest with people. It is therefore essential that the solution and its presentation shall be both easy to understand and intuitively appealing. This need for simplicity and clarity is so great that it may well be worth sacrificing 'performance' for intelligibility. An optimal solution which cannot be comprehended by the person responsible

for its implementation may well be a failure in practise, whereas a non-optimal but comprehensible solution will stand some chance of being accepted and implemented.

Interactive scheduling is a solution to the problems of practical scheduling. An interactive scheduling package is developed to give visual representation of the schedules built by the different heuristics. It has features to perform priority and partial priority scheduling and also other features to take care of some of the pratical aspects of scheduling. It is felt that such a package will of of great assistance to build effective practical schedules by accomodating changes rapidly and giving more flexibility to the schedule building exercise.

Though not all the practical aspects are taken into consideration in the proposed solution methods proposed, efforts were made to include certain basic practical aspects. In the development of the heuristics two practical aspects, producing a feasible schedule rapidly and schedule intelligibility were taken into consideration. While the interactive scheduling package takes care of the practical aspects of flexibility to adapt to changes rapidly and also take care of the priority and partial priority scheduling.

The approach used in this work is a focused centralised approach with an option of interactive scheduling as an aid to overcome some of the problems like changing priorities, need for rescheduling, and other unplanned developments that occur so often in practise.

CHAPTER 2

BACKGROUND

The majority of work performed on the weighted tardiness problem has revolved around the single machine case. This problem was shown to be NP-Complete. Approaches like dynamic programming and branch and bound tend to be impractical for large problems. As far as heuristics go, the Ramachamadugu & Morton heuristic [27] has proven to be far superior to other known heuristics and has been shown to come very close to optimal in more test problems where either the optimal solution or a lower bound could be found.

In the case of scheduling in flow shops, a majority of research efforts has been directed towards the makespan problem, either in developing heuristics or in attempting to gain some insight into the algorithmic procedures. The main approaches to the solution of the flow shop scheduling problems had been to develop solution procedures using branch and bound technique, dynamic programming, networking and decision rules built using some criteria based on the objectives. In attempting to use the branch and bound procedure in evolving a solution to the flow shop problems efforts were made to develop better bounds. McMohan and Burton [21] referred to lower bound as a machine-based bound in that the bound is determined for unsatisfied requirements on the machines. They also used a complimentary approach called the job-based bounds which are determined from unsatisfied requirements of the unscheduled jobs.

Bestwick and Hastings [3] introduced a new machine-based lower bound with respect to the partial sequence of jobs on machines in flow shop scheduling problems. The calculations of their machine-based bounds in branch and bound procedure depend on arranging free jobs on a machine in a sequence where jobs are arranged in order of decreasing lags of free jobs relative to the machine. Such an ordering of free jobs on a machine minimizes the maximum over-run of freejobs on the suceeding machines. Bansal [2] introduced a new concept of 'maximum effective pre- processing time of jobs for the last machine' and developed a new lower bound on machines without presequence of jobs.

Nabeshima [22] developed a set of sufficient conditions for determining the definite order of adjacent two jobs for the min-makespan problem in flow shops where no passing is allowed by using dynamic programming formulation.

Gupta and Maykut [14] developed a schedule evaluation algorithm for the scheduling of n jobs on m machines in a flow shop to minimize the throughput time of all jobs under the assumption that all jobs are processed on all machines in the same order. The schedule evaluation algorithm, which consists of annotating the process time array, is based on the mathematical formulation of the job and machine slacks. The algorithm uses the concept of synthetic job to represent a partial sequence and identifies those jobs that are critical to the completion time of any job, yeilding critical paths. It also illustrates the manner

in which job and machine slacks propogate through the flow shop.

For solving general scheduling problem order-assignment model was proposed by Yamamoto [32]. In the order-assignment model scheduling is viewed as the selection of resource orders which are assigned for the purpose of resolving resource constraints and the sequence of their selection constructs a search tree. Each job is represented by a set of operations which are necessary for the completion of the job. A network is formed by technological order between the operations of a group of jobs. By introducing resource orders to this network a feasible solution which satisfies constraints of available resources can be obtained. The selection of optimal order for a given objective function gives the solution to the scheduling problem. Yamamoto proposed an algorithm for searching the optimal schedule based on branch and bound technique.

The concept of 'Generalised ordered schedule' was advocated by Bestwick and Lockyer [4] as a means of achieving intuitive appeal and improved control. In generalised ordered schedule, the sequence in which jobs are allocated for the first operation is repeated for all operations. The generalised ordered schedule thus provides a job sequence which is maintained on all machines throughout the manufacturing cycle. This reduces the number of feasible schedules from $(n!)^m$ non-ordered schedules to $n!/(2^r)$ ordered schedules, where r is the number of precedence constraints. The search for the optimal or near optimal solution is done using branch and bound.

A lot of research effort has also gone into development of heuristics for flow shop problems. A number of heuristics based on the Jhonson's algorithm for the 2-machine n-job problem has been developed. Palmer [25] developed a heuristic, to minimize the make-span in flow shop problems, which gives greater priority to jobs having a stronger tendency to progress from short times to long times in the sequence of operations and a permutation schedule is built using the job ordering. Gupta [10] developed a generalisation of Johnson's rule for the 3-machine case, to develop a transitive job ordering to produce good make-span schedules.

The most significant heuristic method for make-span problems using modification of Johnson's algorithm was developed by Campbell, Dudek and Smith [5] called the CDS heuristic. It uses Johnson's rule in a heuristic fashion and generally creates several schedules from which a 'best' schedule can be choosen. The CDS algorithm corresponds to multistage use of Johnson's rule applied to a new problem, derived from original. At each stage the job order obtained is used to calculate a makespan for the original problem and the best schedule identified.

Several heuristics using search in one form or other were also developed. Krone and Steigliztz [14] developed a two phase search method to the mean flow time problem. In the first phase search is confined to the set of order preserving schedules. in the second phase the schedule produced by phase one is subject to deviation from uniform ordering till there is no improvement.

Page [24] developed a heuristic based on the Johnson's 2- machine algorithm and sorting techniques. The initial schedule is built by using Johnson's algorithm in calculating an address index for each job and ordering the jobs based on the address index. He also developed sorting techniques merging, pairing, individual exchanging and group exchanging for improving the solution. Dannenbring [6] developed a heuristic that generates good starting schedules and improves them by neighbourhood search methods rapid-access (RS), rapid-access with close search (RACS) and rapid-access with extensive search (RAES).

Despite the importance of the tardiness problem, little work has been done beyond the development of simple despatch rules such as the COVERT rule, slack per remaining processing time rule and earliest due date rule. COVERT a simple dispatch rule originally was used for minimizing unweighted tardiness in flow shop problems. It was later modified by Vepsalainen et al., [29]. In this when a machine becomes free the priority index of all the jobs in its queue is calculated. The priority calculation is based on the anticipated queuing time of the job at the machine, the remaining processing time of the job, due-date, and the process time of the job. Vepsalanien, Ramachamadugu and Morton [29] developed the Lead Time Iteration for the proportionate flow shop weighted tardiness problem. Though the procedure is computationally simple, $O(n^2 m)$, for each iteration, the convergence towards a 'locally' optimum solution is not guaranteed. The complexity of the method depends on the rule used to decide when to stop iterating.

In the last few years, some unusual approaches have been taken towards scheduling including the use of knowledge based scheduling systems with elaborate search mechanism that have typically been used in artificial intelligence, in an attempt to address almost all aspects of the actual problem, rather than the simplified abstraction of the problem.

A simple and very logical approach to the proportionate flow shop problem was suggested in a recent work by Peng Si Ow [26] called the Focused Approach. The focused approach also proved more effective than the other approaches in tackling the weighted tardiness problem. The focussed approach exploits the structure of the flow shop in two ways:

(i) This structure makes permutation schedules good approximations to the optimal solutions and also for pratical considerations like intelligibility to be dealt with later.

(ii) The production in a flow shop at a given time is controlled by the resource which happens to be the bottleneck resource.

In a proportionate flow shop the bottleneck machine is easily identified and is stationary, in the sense that the bottleneck machine will be the same machine irrespective of the mix of jobs to be processed. It was shown that the focussed approach performed better than the dispatch methods - COVERT, EDD, WSPT and FCFS - and Lead Time Iteration method in tackling the problem of weighted tardiness in proportionate flow shops.

In a general flow shop with multiple job groups, the problem of identification of bottleneck is not a trivial one. It was felt that the focused approach which has been proved to be effective for the weighted tardiness problem in proportionate flow shop should be extended to the general flow shop with multiple job groups.

The practical aspects of scheduling which seem to have been neglected by past researchers in scheduling were studied by Gupta [10] - [13]. Bestwick and Lockyer [4] conducted field research to find out the requirements of any useful practical scheduling system. Interactive scheduling is an approach to pratical scheduling. Godin [8] studied the history and the state of the art of interactive scheduling. Hodgson and McDonald [15] developed a successful interactive scheduling for a practical problem.

CHAPTER 3

DEVELOPMENT OF HEURISTICS

The solution procedures using the focussed approach to scheduling of jobs in general flow shops can be as said to have two distinct stages. First the bottleneck has to be identified and next the job to be scheduled with respect to the identified bottleneck machine has to be selected. Solution procedures have been developed with the objective of minimizing overall weighted tardiness of the jobs scheduled in a flow shop.

The approach to the scheduling will consist of developing a permutation schedule in which a job will be added to the partially constructed schedule. Job selection will be based on computation of priority numbers for each of the unscheduled jobs. These priority numbers are computed based on the idle time induced on the current bottleneck machine. Identification of the botttleneck machine is a dynamic procedure in general flow shops and three different rules are developed for selecting such bottleneck machines.

Three heuristics each using one of the rules for identification of the bottleneck machine and the idle time on bottleneck machine to calculate the priority measure are developed. A fourth heuristic is also developed in which the job priority is computed based on the idle time induced on all the machines. In summary the heuristics are classified as follows:

	Bottleneck Identification Rule	Job Selection Rule
Heuristic:1	Bottlenack Criteria Rule	Idle Time Rule
Heuristic:2	Remaining Work Load Among All Machines	Idle Time Rule
Heuristic:3	Remaining Work Load Among Identified Machines	Idle Time Rule
Heuristic:4	Bottleneck Criteria	Modified Idle Time Rule

3.1. Development Of Bottleneck Identification Rules:

As stated earlier the bottleneck machine may be dynamic in a general flow shop. The bottleneck in general can be defined as the machine or machines that controls the output from the shop. In flow shop the bottleneck machine is one that forces succeeding machines to be idle because it is unable to complete and release jobs for succeeding machines to process whenever these later machines are free. To make the definition clear, not each machine which forces the succeeding machine or machines wait can be termed as bottleneck machine. There may be many minor bottleneck machines which delay the release of jobs to the succeeding machine or machines, but still not delay the flow of jobs from the line. Therefore only the machine which effectively delays the flow of jobs from the line is the bottleneck machine.

In flow shops where all the jobs have the same proportionate requirement of the machines, called the proportionate flow shops, the bottleneck machines are stationary and easily identified. In a proportionate flow shop the bottleneck is always the machine at which the processing times for all the jobs are longer than at any other machine. The identification of the bottleneck machine is thus simple and the focused approach makes use of this characteristic of the proportionate flow shops. In the focused approach, once the bottleneck machine is identified, the information on the bottleneck machine is made use of in tackling the weighted tardiness problem.

In order to extend the focused approach to the general flow shop problem the bottleneck, which may be dynamic, must be identified before the information on the bottleneck machine can be used. In the the general flow shop it is difficult to say which machine or machines will control the flow of jobs from the shop. Also the machine or machines which control the bottleneck may not remain the same through-out the scheduling period. The bottleneck will also depend on the actual jobs to be processed and also the schedule being built up. Thus it will be very difficult to identify the bottleneck machine before building the schedule or while the schedule is being built up. Therefore it was decided to develop a rule to identify the likely bottleneck at each instant in which a scheduling decision is to be made. The likely bottleneck machine will be refered to as the bottleneck machine in the rest of the discussion. Three rules

are developed to identify bottlenecks in flow shops. They are

(i) Bottleneck criteria rule

(ii) Remaining work load among all the machines rule

(iii) Remaining work load among identified machine rule

These rules are discussed in the following sections.

3.1.1. Bottleneck Criteria Rule:

The bottleneck criteria rule is aimed at identifying the machine which has the least available free time at any given instant of time when a scheduling decision is to be made. According to this rule the machine which has the least available free time will be the bottleneck machine. The idea behind this is that the machine which has the minimum available free time must not be allowed, as far as possible,to remain idle. Though the main objective is to minimize the overall weighted tardiness of the jobs to be scheduled, the time saved on a critical bottleneck machine may actually reduce the tardiness of several jobs to be scheduled later. In order to measure the available free time of the machines, a criterion called 'Bottleneck Criterion' has been developed. The bottleneck criterion is developed for the two distinct cases of single due date for all the jobs and of multiple dates.

Bottleneck criteria for single duedate case

As the first part of the development of bottleneck criteria rule, the single duedate problem has been considered. This simplified the problem and laid a basis for the extension to

the multiple duedate case.

The bottleneck criterion of a machine has two components; the available time and the remaining work load. The available time depends on the late finish time and the early start time of the machine. Late finish time of a machine may be defined as the latest point in time till which the machine can be used so as to be able to meet the due date. As the determination of the exact late finish time will depend on the schedule being built up, only a measure of the late finish time is used. The late finish time is not the same for all the machines because allowance has to be made to the processing time in the succeeding machines. The late finish time of a machine depends on the due date and the processing times of the unscheduled jobs in the subsequent machines. The late finish time of the last machine will be the due date and that of the preceeding machines will be the late finish time of the next machine less the average processing time of the unscheduled jobs in the next machine. The early start time of a machine is the time at which a job can be scheduled on the machine. It is dependent on the jobs already scheduled. The effective processing time of a job on a machine is the sum of the processing time of the job on the machine and the idle time forced on the machine by the job. The early start time is the sum of the effective processing time of all the scheduled jobs. Thus the calculation of late finish time and early start time are completely independent of one another. The available time of a machine is late finish time less early start time of the machine. The remaining work load on a machine is the sum of

the processing time of all the unscheduled jobs on the machine. The available free time on a machine is equal to the available time less remaining work load on the machine. A figurative representation the problem and the terms used in the discussion is given below.

The notation to be used

s-	..	set of unscheduled jobs
s	..	set of scheduled jobs
ESP_i	..	early start time of machine i
LF_i	..	late finish time of machine i
P_{ij}	..	processing time of job j on machine i
I_{ij}	..	idle time forced by job j on machine i
EP_{ij}	..	effective processing time of job j on machine i
APT_i	..	average processing time of the unscheduled jobs on machine i
DD	..	due date
AVT_k	..	available time on machine k
RW_k	..	remaining work load on machine k
BNC_k	..	bottleneck criterion of machine k

ES_i = sum (j belongs to s) P_{ij} + sum(j belongs to s) I_{ij}

= sum (j belongs to s) EP_{ij}

LF_i = DD - sum((k varies from i+1 to m)

average((j belongs to s-)P_{kj}))

$AVT_k = LF_k - ES_k$;

RW_k = sum(j belongs to s)P_{kj}

$BNC_k = AVT_k - RW_k$

Diagramatic representation of the single due date problem

```
                                             LFm-2      LFm-1   LFm
                                               :          :      |
                                               :          :      |
Machine                  |                     :          :      |
                         |                     :          :      |
                        _|_________   AVTm-2   : APTm-1   :      |
                         |    /    |<--------->:<------->:      |
Machine m-2              |  /   /  |                      :      |
                        _| /   /   |______     AVTm-1     : APTm |
                         |   /   /.    /   |<------------>:<---->|
Machine m-1              | /    / .  /  /  |              :      |
                        _|  scheduled /  |__________     AVTm    |
                         |  /machine /  /.  /   /  |<---------->|
Machine m                |/  time ./   / . /  /  /|              |
( Last machine)         _|_________.______.________|_____________|
                                ESm-2    ESm-1      ESm   Due date(DD)

                                     Time -->
```

Bottleneck Criterion for multiple due dates:

When there are multiple duedates the bottleneck criteria is calculated by breaking the problem into single duedate problems. A single duedate problem is formed for each of the distinct duedates from the set of duedates of unscheduled jobs. Each sub-problem formed will have its set of jobs as the unscheduled jobs with due date less than or equal to the due date under consideration. Each sub-problem generates a bottleneck number for each of the machines. These bottleneck numbers are then added machine-wise with weight inversely proportional to the duedate of the sub-problem. The justification for the weightage

chosen is that the bottleneck number for each machine gives a measure of the free time available and the free time available at a later point in time must be given less weightage than the free time available at an earlier instant.

The notation to be used :

m .. number of machines

n .. number of jobs

D_i .. distinct due dates, i=1 to p ,p<=n

$RW_k(D_j)$ .. remaining work load on the machine k till the due date D_j

$AVT_k(D_j)$.. available processing time on the machine k till the due date D_j

EP_{kj} .. effective processing time on machine k of job j

I_{kj} .. Idle time forced by job j on machine k

P_{kj} .. processing time of job j on machine k

ES_k .. early start time on machine k

$LF_k(D_j)$ .. late finish time on machine k with respect to the due date D_j

$s^-(D_j)$ .. set of all unscheduled jobs with due dates <= D_j

s .. set of all scheduled jobs

BNC_k .. bottleneck number of machine k

EP_{kj} = sum({j belongs to s}P_{kj} + I_{kj})

ES_k = sum{j belongs to s} EP_{kj}

$LF_k(D_j)$ = D_j - sum({i varies from k+1 to m} average({l belongs to $s^-(D_j)$} P_{il}))

$RW_k(D_j)$ = sum{l belongs to $s^-(D_j)$ } P_{kl}

$AVT_k(D_j)$ = $LF_k(D_j)$ − ES_k

BNC_k = sum{j varies from 1 to p }(($AVT_k(D_j)$ − $RW_k(D_j)$)/D_j)

Once the bottleneck number are calculated, the machine which has the least bottleneck number, meaning the machine which has the least available free time, is identified as the bottleneck machine.

Bottleneck machine = k

where k is such that

BNC_k = min {i varies from 1 to m} BNC_i

3.1.2. Remaining work load among all machines rule

This is a simple rule which identifies the bottleneck machine using the remaining work load of the machines. Remaining work load of a machine is the sum of the processing times of all the unscheduled jobs on the machine. At each instant when a job is to be scheduled the remaining work load for all the machines is calculated. The idea behind this rule is to reduce the forced idle time on the machine having the maximum work load. The machine which has the maximum remaining work load is identified as the bottleneck machine.

Using the above notations:

Remaining work load of machine k

= RW_k = sum{j belongs to s^-} P_{kj}

Bottleneck machine = k

where k is such that

RW_k = max{i varies from 1 to m} RW_i

3.1.3. Remaining work load among identified machines

In the proportionate flow shop case the bottleneck is the machine which has the longest proportionate requirement. In the case of flow shop with multiple job groups, the longest proportionate requirement machine may be different for different jobgroups. This rule is a direct extension of the the rule used to identify the bottleneck in the proportionate flow shop. In this rule, in a flow shop, the machines which have the longest proportionate requirement for atleast one job group are identified to be the possible bottleneck machines and the search for the bottleneck machine is limited to these machines. The remaining work load is used as bottleneck identifying criteria among the machines which have the largest proportionate machine time requirement for atleast one job group.

Let m- .. set of machines k which have maximum proportional requirement for atleast one job group.

Bottleneck machine = k

where k is such that

RW_k = max {i belongs to m-} RW_i

3.2. Job selection rules

Once the bottleneck is identified using any of the above rules, a decision is to be made on the job to be scheduled. Here the objective will be to select that job which will reduce the overall weighted tardiness by giving due consideration to the job duedate and the forced machine idle time that will result if the job is scheduled. Two rules (1) idle time rule apodted from the focussed approach to proportionate flow shops and (2) a modification of the idle time rule were used. The two rules are discussed below.

3.2.1. Idle Time Rule

Idle time rule was developed by Peng Si Ow [26] for the selection of jobs to be scheduled in proportionate flow shop case. This rule which performed well in the proportionate flow shop problems was adopted for the job selection in three of the solution procedures for the scheduling of the general flow shop. The function for calculating the job priorities in the idle time rule and the terms involved and their significance are discussed below.

Each time when a job is to be scheduled the priority of the jobs are calculated. The priority of a job depends on the earliness of the job, the idle time the job forces on the bottleneck machine, the weight associated with the job, and the processing time of the job on the bottleneck machine. The priority of a job i at time t is denoted as PRi(t).

Let

$$expfactor = e^{-[((D_i - F_i)^+ + h * (S_i^+ - S))/(k * (MP + S))]}$$

$$PR_i(t) = (W_i / (P_{ib} + S_i^+) * expfactor$$

where

D_i .. due date for job i

F_i .. finish time of job i if scheduled at this instant

W_i .. weight of job i

P_{ib} .. process time of job i on the bottle neck machine b

S_i^+ .. idle time forced by job i on the bottleneck machine

S .. mean forced idle time on the bottlenack machine

k .. look ahead parameter

h .. resource parameter

MP .. mean processing time of all the unscheduled jobs on the bottleneck machine

The term $(S_i^+ - S)$ in the priority function estimates the difference between in the forced idle time between scheduling job i now and scheduling it later. 'h' is called the resource parameter. Its role is to reflect the oppurtunity cost of a time unit saved on the bottlenack machine ie., the cost savings that would result if an extra unit of machine capacity was available at time t. The parameter k is called the look ahead parameter. An increase in k increases the span of consideration ie., tends to look beyond the immediate jobs. In order to differentiate between jobs during the initial 'zero priority' phase, the priority function uses the exponential function. This enable the jobs to be differentiated from the time scheduling starts.

2.2 Modified Idle Time Rule

In the idle time rule the idle time on the bottleneck machine alone is taken into consideration. The reason being the idle time on the machines other than the bottleneck machine is of little significance in the proportionate flow shops case. This is so because there is only one bottleneck machine which controls the flow of jobs from the shop through-out the scheduling period.In a general flow shop the bottleneck is dynamic. A machine which is not a bottleneck machine at a particular instant of time may become a bottleneck at a later point in time. Any effort to reduce the forced idle time on non-bottleneck machines may result in the saving of machine time on some future bottleneck machines. Any reduction of the forced idle time on a future bottlenack machine may increase its availability, which may in turn result in reducing the tardiness of the jobs to be scheduled later. It is this motivation that led to the development of the modification of the idle time rule.

While considering the forced idle time on the non-bottleneck machines it is imperative that no undue importance is given to the forced idle time on the machines which may never control the flow of jobs from the shop. In fact the forced idle time on the machines can be very misleading. For example, a machine with a low proportional requirement for all the job groups will have a low machine utilization factor. This means that the machine will remain idle for a greater proportion of the time. But any effort to reduce the idle time on such machines will be of little help as they will not control the flow of jobs

from the shop. Thus it may not be advantageous to reduce the forced idle time on any arbitrary machine. Therefore any method proposed to give importance to the forced idle times on the non-bottleneck machines must be able to distinguish between the machines by identifying the potential future bottleneck machines and giving them due importance.

A modification of the idle time rule called the modified idle time rule has been developed. Its takes into consideration the forced idle time on the non-bottleneck machines. Here the aim is to reduce the sum of the weighted forced idle time on all the machines. The weightage proposed is the square of a measure of the criticality of the machines. A machine is said to be more critical if it has lesser available free time. As already stated the bottleneck criteria is a measure of the free time available. The values of the bottleneck criteria for each job at each point of scheduling decision is transformed so that the most critical machine takes the value equal to one and the other machines taking values between zero and one. The function to do this transformation is given below.

Let

BNC_k .. the bottleneck criteria for the machine k

$NBNC_k$ .. the normalised bottleneck criteria of the machine k

$IDTW_k$ .. the weight attached to the idle time on machine k

HBNC .. the highest value of bottleneck criteria among all machines

LBNC .. the lowest value of bottleneck criteria among all machines

CRMCk .. criticality of the machine k

First the bottleneck criteria of all the machines are normalised by the following function

$$NBNCk = (BNCk - LBNC) / (HBNC - LBNC)$$

Then the criticality and the weightage for the machines are calculated as follows

$$CRMCk = 1 - NBNCk$$

$$IDTWk = (CRMCk)^2$$

CHAPTER 4

COMPUTATIONAL STUDY

The computational study in this work is done in two stages. In the first stage experiments are done to study the effects of two parameters, look ahead and resource constant. In the second stage the heuristics developed are compared with two dispatch rules. For conducting the experiments problems are to be generated. The problem design used in the experiments, the study of parameters and the comparison of heuristics are discussed in the following sections.

4.1. Problem design

The problems are designed to emulate flow shops with multiple job groups. The problem to be described is used in the study of parameters and comparison of heuristics. Before describing the actual problem design, the terms to be used in it have to be made clear. The proportional requirements of the machines for a job is the 'Constant of proportionalities'. A 'Job group' consists of jobs which have the same constant of proportionalities. That is, all the jobs which belong to the same group will have the same proportional machine requirements. In flow shop, with multiple jobgroups, jobs are processed in batches. 'Job size' is a measure of the batch size. Though two or more jobs may belong to the same job group, and have the same proportional requirements, depending on the job size they may

have different 'Processing- time' requirements. The problem generation is discussed below in detail.

Constant of proportionality (C_{ij}): Sets of constant of proportionalities are generated. The number of such sets being equal to the number of job types/groups. Each constant of proportonality is chosen from a uniform distribution (0,1). In each set so generated the proportionalities are multiplied by a number as to make the maximum amongst them equal to one.

Job size (S_i) : Job sizes are chosen from a uniform distribution (5,20). For each job a job size is generated.

Process times (P_{ij}) : Process times of a job can be got by multiplying the constant of proportionalities of the job by its size. But to accommodate for the usual processing time deviations that occur in practise the process times are chosen from a uniform distribution ($C_{ij} \times S_j(1 - p/2), C_{ij} \times S_j(1+p/2)$), where $p/2$ is the deviation allowed on either side of the mean ($C_{ij} \times S_j$).

Due dates (D_j) : Due dates are generated using duedate mean, tardiness factor and duedate range. Tardiness factor is a measure of the the percentage of jobs which might be expected to be tardy, the higher the tardiness factor the lower the duedate mean and hence greater the percentage of jobs tardy expected. Due date mean is calculated from a measure of the ideal completion time and tardiness factor. The ideal completion time is calculated as the sum of the total processing time of the machine which has the maximum total processing time, and the

average processing times of the other machines. This ideal completion time is shifted to the left by the tardiness factor to get the duedate mean. Duedates are then generated from a uniform distribution with mean as duedate mean and range as duedate range.

Let

Tou - tardiness factor

R - duedate range

k be the machine such that

$$\text{sum}\{j \text{ varies from 1 to } n\}P_{kj} = \max\{i \text{ varies from 1 to } m\} \text{ sum}\{j \text{ varies from 1 to } n\}P_{ij}$$

$$\text{Duedate mean (DDM)} = (1-\text{Tou}) \times (\text{sum}\{j \text{ varies from 1 to } n\}P_{kj} + \text{sum}\{i \text{ varies from 1 to } m, i \# k\} \text{ Avg}\{j \text{ varies from 1 to } n\}P_{ij}$$

D_j is generated from U(DDM(1-R/2),DDM(1+R/2)).

The inputs to problem generation are:

(1) number of jobs

(2) number of machines

(3) number of jobtypes

(4) tardiness factor

(5) duedate range and

(6) processtime deviation

The sequence of steps in the generation of the problems is as follows:

(1) A set of constant of proportionalities is generated for each job group

(2) The constant of proportionaties are adjusted so that the maximum among each set is equal to one

(3) A job size for job is generated

(4) Processtimes for each job are obtained

(5) Due date mean is calculated

(6) Due date for each job is generated

4.2. Study Of Parameters

The job selection rules of the heuristics developed use look ahead parameter and resource constant parameter. Experiments are conducted to study the behaviour of the two parameters with respect to the weighted tardiness criteria. The problems used in this set of experiments are described in the previous section. The problem generation involves five variables viz., number of machines, number of jobs, number of job types, due date range and tardiness factor. Ten sets of problems are considered to study the effects of the parameters look ahead and resource constant. They are given below:

	Machines	Jobs	Job types
(1)	4	20	3
(2)	4	20	20
(3)	8	20	3
(4)	8	20	20

	Machines	Jobs	Job types
(5)	5	30	5
(6)	5	30	30
(7)	10	30	5
(8)	10	30	30
(9)	15	50	7
(10)	15	50	50

For each of the above problems, different scenarios of due date range and tardiness factor were considered. Initially experiments were conducted for the 8, 10 and 15 machine problems. For each of these problems the test data generated are classified into the following nine scenarios.

	Due Date Range	Tardiness factor
(1)	0.6	0.1
(2)	0.6	0.5
(3)	0.6	0.9
(4)	1.1	0.1
(5)	1.1	0.5
(6)	1.1	0.9
(7)	1.6	0.1
(8)	1.6	0.5
(9)	1.6	0.9

For the 5 and 10 machine problems, the scenarios considered are as follows:

	Due Date Range	Tardiness factor
(1)	Ø.6	Ø.1
(2)	Ø.6	Ø.3
(3)	Ø.6	Ø.5
(4)	Ø.9	Ø.1
(5)	Ø.9	Ø.3
(6)	Ø.9	Ø.5
(7)	1.1	Ø.1
(8)	1.1	Ø.3
(9)	1.1	Ø.5

Thus 1Ø problems each in nine scenarios has been studied. The test values for the look ahead are Ø.5, 1, 2, 3 and 5. Test values for resource constant are Ø.5, 1, 3, and 8. Smaller problems i.e., 2Ø job and 3Ø job problems are run for 25 tests while the bigger 5Ø job problems are run for 1Ø tests for each scenario. In order to make the results comparable, the weighted tardiness are normalised to get normalised weighted tardiness. Normalised weighted tardiness is obtained by dividing the weighted tardiness by the mean weighted tardiness of each test problem.

The main effort is directed to

(1) to infer the general nature of the normalised weighted tardiness curve with respect to the changes in values of look ahead and resource constant.

(2) to infer the effect of the machines, number of

jobs and number of job types on the optimal range for look ahead and resource constant.

(3) to measure the effect of look ahead and resource constant on the weighted tardiness in the scenarios considered.

From the results of the experiments it can be said that the normalised weighted tardiness decreases, reaches a minimum and increases as the values of look ahead and resource constant are increased. Sample graphs showing the general nature of the curves is shown in the Fig. 1 and 2. The effect of machines, jobs and job types on the optimal ranges for look ahead and resource constant is not very clear. Table 1 to Table 2 show the effect of the machines and job types on the optimal ranges of look ahead and resource constant. It is difficult to draw any inference on the effects of the machines job types from the results of the experiments conducted. This may be because a number of interelated variables are involved in the problem. But an important inference from the results is that in most cases the optimum lies in the ranges considered for experimentation. With the knowledge that the nature of the curve is U shaped and that the optimum lies in a small range, it can be said that a search can be conducted sucessfully in the ranges for look ahead and resource constant to get optimal or near optimal values for any specific problems.

It can be inferred from Table 2A that the effect of

lookahead and resource constant on the normalised weighted tardiness:

(1) decreases with increase tardiness factor

(2) decreases with increase in due date range

(3) decreases with increase in the product of the number of jobs and number of machines, a measure of problem size.

Thus the need for search for the optimal values of look ahead and resource constant is more in cases of small problems, low tardiness factors and small due date ranges than in cases of large problems, high tardiness factors and large due date ranges.

Selection of Parameters:

Though it is not possible to derive any generalisation for the optimal values or optimal ranges for the parameters, look ahead and resource constant, the results of the experiments conducted show that the search for finding the optimal or near optimal values of the two parameters can be conducted sucessfully for the individual problems. The search can be limited by the needs of the user. In the interactive scheduling system the user can select the range and the number of problems to be solved in the range specified in order to search for the optimal. After the initial search, the user can specify a smaller range for further search. This can be continued till the user feels that the solution is near optimal.

4.3. Comparison Of Heuristics:

In this part of the study the four heuristics developed are compared with two dispatch rules, EDD and WSPT. In the study of parameters it was found that for large problems the effect of the parameters, look ahead and resource constant are minimal. Therefore, this study is limited to large problems so that errors in the selection of the values for the parameters look ahead and resource constant does not have much effect on the results. The number of jobs is fixed at a constant 50, while the number of machines and job types are varied. Nine combinations of machines and job types are used in the comparison of heuristics. In each combination 9 scenarios are considered.

The machine and job type combinations are

Job types	Machines
7	5
7	10
7	15
15	5
15	10
15	15
50	5
50	10
50	15

The scenarios considered for each of the above combinations are

Due Date Range	Tardiness Factor
Ø.6	Ø.1
Ø.6	Ø.5
Ø.6	Ø.9
1.1	Ø.1
1.1	Ø.5
1.1	Ø.9
1.6	Ø.1
1.6	Ø.5
1.6	Ø.9

The six heuristics are considered for the comparative study. The heuristics are referred by their numbers as listed in the table that follows.

	Bottleneck Identification Rule	Job Selection Rule
Heuristic:1	Bottleneck Criteria	Modified Idle Time Rule
Heuristic:2	Bottleneck Criteria Rule	Idle Time Rule
Heuristic:3	Remaining Work Load Among All Machines	Idle Time Rule
Heuristic:4	Remaining Work Load Among Identified Machines	Idle Time Rule
Heuristic:5 (EDD)	--	Earliest Due Date
Heuristic:6 (WSPT)	--	Weighted Shortest Processing Time

As weighted tardiness is the measure to be studied to study the effect of the job weights on the performance of the heuristics computations is conducted for two cases. In the first case the job weights are made equal to the job size and in the second all jobs are given equal weight. Thus a total of 81 problems each for two cases of job weights are used for comparing the heuristics. In order to make the results comparable across the problems the weighted tardiness is normalised by dividing the weighted tardiness by the mean weighted tardiness. This enabled the comparison of the results of the various scenarios and the problems and derive meaningful results out of the same.

Analysis of Results:

Effort is directed to identify the best performing heuristic in each of the problems. The aim being to recommend a particular heuristic for a particular class of problems. The classification of the problem is based on job types, number of machines, due date range and tardiness factor. Table 1.1 - 1.9 and Table 3.1 - 3.9 of the appendix show the effect of job types and machines on the performance of the heuristics for the two job weight cases. From the tables it can be seen that there is considerable effect of the job types on the performance of the heuristics. Table 2.1 - 2.9 and Table 4.1 - 4.9 of the appendix show the effect of range and tardiness on the performance of heuristics for the two job weight cases. It can be seen that a tardiness does affect the performance of heuristics to a great extent. The general inferences from the tables can be summarised as follows:

(1) Heuristic 1 performs well for higher tardiness and its performance also improves for larger job types. Though all the heuristics using the focused approach performed better than the dispatch rules for high tardiness, the better performance of heuristic 1 can be because of the importance attached to the idle time on all machines.

(2) For medium tardiness no particular heuristic can be said to perform better than others in all the scenarios considered, but overall the heuristics using the focused approach perform significantly better than the dispatch rules.

(3) For low tardiness, though the difference in terms of the average weighted tardiness is low, heuristics 3, 4 and 5 perform better than the others. The better performance of the EDD emphasises that, less importance must be attached to the idle time on the machines in the problems of low tardiness. Also it may be that the concept of bottleneck loses its importance because in the cases of low tardiness it may happen that there is no real bottleneck machine.

(4) The effect of range on the performance of the heuristics is much less as compared to that of the tardiness.

(5) The better performance of the heuristic 1 in cases of larger number of job types is expected. With the

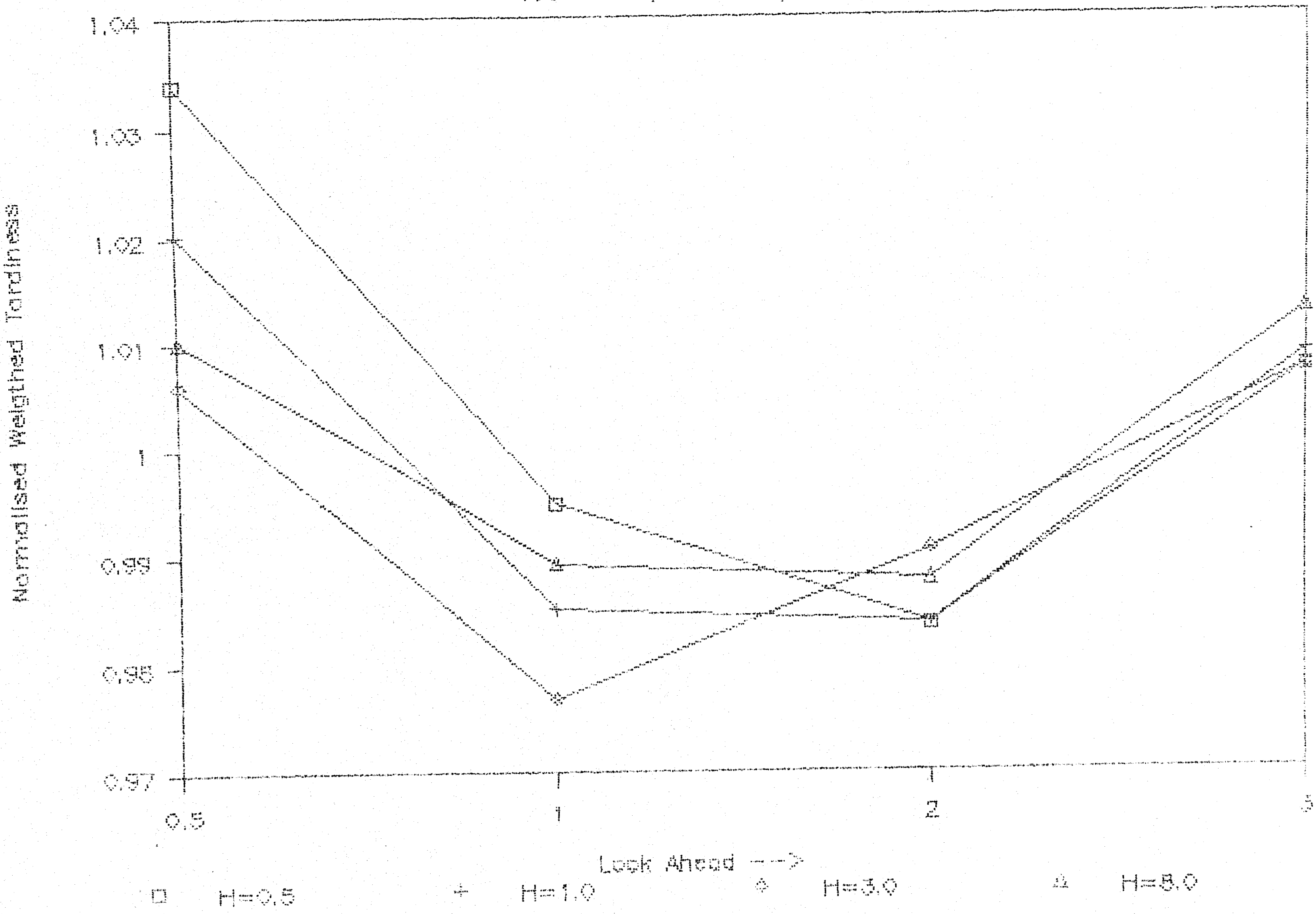
increase in the number of job types the number of potential bottleneck machines increases thus the importance attached the idle time on the non-bottleneck machines in heuristic 1 carries more meaning, resulting in its better performance.

(6) Job weights do not affect the performance of the performance of the heuristics considerably in the two cases considered. This makes the recommondation of the heuristics more general.

Table 3 gives the recommendations for selection of the heuristics for different classes problems based on the results of the computations.

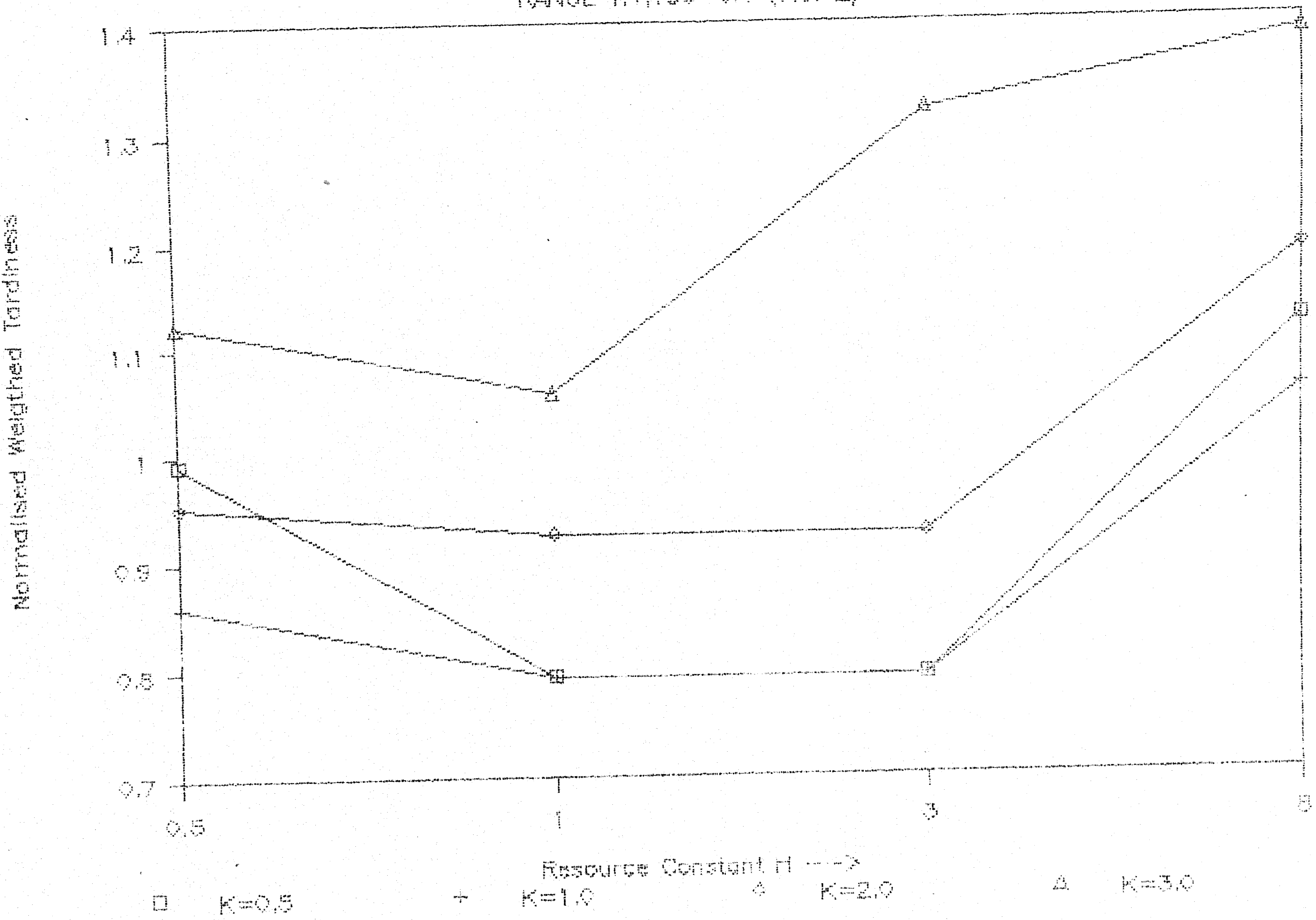
EFFECT OF LOOK AHEAD K

RANGE 1.5,TOU=0.5 (FIG. 1)



EFFECT OF RESOURCE CONSTANT 'H'

RANGE 1.1,TOU=0.1 (FIG. 2)



EFFECT OF MACHINES ON THE OPTIMAL RANGE OF LOOK AHEAD(K) AND RESOURCE CONSTANT(K)

RANGE = 1.1, TARDINESS = Ø.5

PROBLEM	OPTIMAL RANGE FOR H	OPTIMAL RANGE FOR K	H*	K*
4,2Ø,3	Ø.5- 8	2 - 5	3	3
8,2Ø,3	1 - 8	1 - 3	8	2
4,2Ø,2Ø	3 - 8+	2 - 5	8	3
8,2Ø,2Ø	3 - 8+	3 - 5+	8	5
5,3Ø,5	1 - 8	2 - 5	3	3
1Ø,3Ø,5	1 - 8	2 - 5	3	3
5,3Ø,3Ø	Ø.5- 2	3 - 5+	1	5
1Ø,3Ø,3Ø	1 - 8	2 - 5	3	3

H* -- The value of H for which the minimum occurred

K* -- The value of K for which the minimum occurred

X+ -- Indicates that the minimum is not reached in the range

TABLE 1

EFFECT OF JOB TYPES ON THE OPTIMAL RANGE OF LOOK AHEAD(K) AND RESOURCE CONSTANT(H)

RANGE = Ø.6,   TARDINESS = Ø.1

PROBLEM	OPTIMAL RANGE FOR 3		3	
	H	K	H*	K*
4,2Ø,3	Ø.5- 8	3 - 5+	3	5
4,2Ø,2Ø	Ø.5- 8	1 - 3	1	2
5,3Ø,5	3 - 8	2 - 5	8	3
5,3Ø,3Ø	Ø.5- 8	2 - 5	3	3
8,2Ø,3	Ø.5- 8	2 - 5	3	3
8,2Ø,2Ø	3 - 8+	2 - 5	8	3
1Ø,3Ø,5	Ø.5- 3	3 - 5+	1	5
1Ø,3Ø,3Ø	1 - 8	2 - 5	3	3
15,5Ø,7	3 - 8	2 - 5	8	3
15,5Ø,5Ø	3 - 8	2 - 5	8	3

H* -- The value of H for which the minimum occurred

K* -- The value of K for which the minimum occurred

X+ -- Indicates that the minimum is not reached in the range

TABLE 2

APPROXIMATE PERCENTAGE ERROR
IN NORMALISED WEIGHTED TARDINESS
FOR THE SCENARIOS CONSIDERED

RANGE	PROBLEM SIZE	TARDINESS Ø.1	TARDINESS Ø.5	TARDINESS Ø.9
	8Ø,15Ø,16Ø	15 - 4Ø	6 - 12	Ø.4 - 1
Ø.6	3ØØ	7 - 9	5 - 6	--
	75Ø	5 - 6	2 - 4	Ø.2 - Ø.7
	8Ø,15Ø,16Ø	7 - 1Ø	4 - 7	Ø.5 - 1.5
1.1	3ØØ	4 - 6	5 - 6	--
	75Ø	4 - 5	3 - 4	1.Ø - 1.5
	8Ø,15Ø,16Ø	6 - 8	4 - 6	Ø.3 - 1.2
1.6	3ØØ	--	--	--
	75Ø	Ø.5 - 2	Ø.5 - 1.5	Ø.2 - 1.4

TABLE 2(A)

PROBLEM X,Y,Z --> X number of machines, Y number of jobs,
Z number of job types

PROBLEM SIZE --> The product of number of machines and
the number of jobs

JOBTYPES	HIGH TARDINESS	MEDIUM TARDINESS	LOW TARDINESS
LOW	HEURISTIC 1	HEURISTIC 2&3	HEURISTIC 4
MEDIUM	HEURISTIC 1	HEURISTIC 1	HEURISTIC 2 & 5
HIGH	HEURISTIC 1	HEURISTIC 1	HEURISTIC 3

TABLE 3: SELECTION OF HEURISTICS FOR DIFFERENT CLASSES OF PROBLEMS

CHAPTER 5

INTERACTIVE SCHEDULING

Scheduling does not stop with using a solution procedure to find the allocation of jobs to machines to meet an objective criteria. In practice rescheduling the schedules just rescheduled is a rule rather than an exception. Interactive scheduling goes a long way in meeting the requirements of practical scheduling.

The schedules generated by a solution procedure may not be acceptable to the scheduler for several reasons. Even those solution procedures which are very effective in meeting the objective laid down may not find application and acceptance in practice. The reasons may be:

(1) some over-riding practical consideration or

(2) the objective framed is not the same or only an approximation of what the scheduler wanted due to either the difficulty in framing the objective or the changing priorties or

(3) the assumptions made in the solution procedure may not hold.

The scheduler would like to incorporate changes in the schedule based on his experience and intuitive appeal. He may like to observe the effect of such changes on the performance measures. Priorities keep changing, a job may have to be taken up earlier than planned or vice versa, because of the changed

requirements. In most cases when a request for urgent jobs come they have to be heeded to without delay. The uncertainity in the availability of materials, manpower and machines also form an important aspect of practical scheduling. It is very much normal that the materials planned to arrive did not arrive in time or that there is a sudden increase or decrease in the power or that there is unplanned machine down time due to machine breakdown. It is difficult to take into consideration all the above aspects in the design of a solution procedure. So it is highly imperative that any scheduling method to be accepted and implemented must have:

(1) enough flexibility to incorporate the changes in priorities

(2) be able to accomodate changes forced by the environment

(3) to be comprehensible and convincing to the scheduler

Interactive scheduling is a solution to the problem of acceptance and implementation of scheduling solution procedures.

Godin [8] surveyed the history and the state-of-the-art in interactive production scheduling. In general, his conclusions were that nearly all if not all of the applications that had been developed upto that point in time had either

(1) failed prior to their being implemented or

(2) being abandoned by the users shortly after becoming operational.

The following is a condensed version of several of the reasons Godin hypothesized for these failures:

- excessive assumptions
- lack of flexibility and sophistication
- lack of user-personnel familiarity with computer-based systems
- unrecognized implications of bad schedules
- commercial unattractiveness of the systems due to
  - (1) Custom design
  - (2) High user training cost
  - (3) Difficult evaluation of cost savings

Hodgson & McDonald [15] developed a computer system for scheduling of aircraft overhauling at a naval depot. They used an 'evolutionary approach' to the system design and development. Their work throws light into the various stages in the development of an effective interactive scheduling system which can be summarized as follows:

(1) Development of the objective criterion based on the objective criterion as envisioned by the management and the responses of the users to different schedules drawn up for a period.

(2) Development of a MIS to meet the likely needs of the system and fine tuning it.

(3) Initial conferences with the users for ascertaining the features and capabilities that are desired for the final product by the users.

(4) Development of prototypes of segments of the

interactive scheduling systems for usage by the users to stimulate the interchange of ideas between the users. This is to enhance the features of the future and final versions of the components and the entire system.

(5) Quantification of the objective function

(6) Development of schedule creation methods

(7) Measurement of system effectivenss.

In the development of the system by them numerous components of the final interactive scheduling system resulted from ideas conceived either solely by the users or by the users working in consonance with the developers of the system. This resulted in a system with far more practical utility than any other possible system would have that was based entirely on a set of specifications created before the beginning of the system design.

Any interactive scheduling system to be successful must be built with the active participation of the actual users. It must be flexible, comprehensible and convincing. It must be able to meet the requirements of practical scheduling.

In this work an interactive computer system is developed to give a feel for the interactive scheduling. An attempt is made to develop a Personal Computer based interactive scheduling system which gives the scheduler enough flexibility to incorporate changes and to study the effect of such changes on the performance measures. The implementation details are discussed in the following sections.

Software Aspects of the System:

The interactive scheduling system that has been developed is written in Turbo Pascal using Turbo Graphics Tool Box. It is developed for IBM Compatible Personal Computers with CGA card. With a little modification it can be adapted to IBM compatible Personal Computers with HGA card.

The salient implementation feature is the creation of 'Virtual Page'. One of the main objectives of the development of the system is to give visual representation to the schedules. The visual representation of the schedules to be effective must be easily comprehensible to the user. Traditionally, Gantt Charts are used by schedulers. Gantt Charts are simple, easy to understand and readily convey the schedule information. It was decided to have the Gantt Chart as the basis for visual representation. The Gantt Charts can be shown as consisting of distinct parts of the schedule or as a continuous one. If the Gantt Chart is shown as consisting of distinct parts, the user may miss continuity. Also, it will be a more natural viewing if a continuous chart representation is given. For this purpose, virtual page is implemented. At any point in time there will be two pages of information, in the form of Gantt chart in the RAM. A connection between the virtual page and the screen memory is established to display the information from the virtual page to the screen. Depending on the requirements of display, pages of information are saved and loaded automatically from the hard disk to the virtual page in the memory.

User Interface:

The package is user friendly and entirely menu driven. Adequate help facilities are provided. The entire package can be viewed as consisting of four distinct parts:

1. Input section
2. Schedule building based on a rule
3. Schedule building based on partial priority
4. Manual scheduling

Input Section:

In the input section, the user will have to input the machine and job information.

Machine information consists of:

1. Number of machines and
2. Machine codes

Job information consists of:

1. Job codes
2. Processing times of jobs in each machine
3. Due dates of jobs and
4. Job weights.

The user is given the choice of either creating a new file to input the above information or to refer to a file in which the information is already available. The information in the file created or in the file selected is used as input to schedule building.

Schedule Building Based on a Rule:

In this the user has the option to choose any of the six heuristics to be used in building a schedule. The user can also ask for information on which heuristic is expected to minimise weighted tardiness for the problem selected. This information will be based on the study conducted in this work. The user can select a particular value of resource parameter and look ahead parameter or can do experimentation in selected ranges to find the optimal values of look ahead and resource parameters.

After selecting a rule the user can view the schedule on the screen, can ask for display job and machine information, can ask for display of performance measures.

Schedule Building Based on Partial Priority:

In this the user is given the option to override the job sequence decided by any scheduling rule. The user will have to select a heuristic to be used in scheduling jobs. The user can partially specify the job sequence and ask the remainder to be scheduled using the heuristic selected. Here also the schedules are limited to permutation schedules. For example, if n jobs are to be scheduled then the user can ask for the job sequence as decided by the heuristic selected. The user can see the display of the schedule on the screen and ask for the schedule performance measures. If the user feels that:

(1) the schedule decided by the heuristic is not performing well or

(2) there is scope for improvement or

(3) the schedule is not acceptable due to some priority considerations.

In such cases the user can decide on a partial sequence and can ask for the remaining jobs scheduled using the heuristic selected. Thus the user may be able to build a schedule which meets his expectations. This reduces the rigidity of the scheduling rules and given enough flexibility to accommodate changes forced by the environment. This also helps the user to compare alternate schedules and see the effect of bad schedules on the performance measures.

Manual Scheduling:

In manual scheduling the user is given complete flexibility to schedule the jobs. Here the schedules are not limited to permutation schedules. The user will have to schedule all the jobs on each of the machines manually. He is assisted by menu driven commands to select, alter and schedule jobs on the screen. He can also ask for relevant information on the machine and jobs. Manual scheduling can be used by the user to make specific changes in the schedules which cannot be made by the partial priority scheduling. The user is assisted in developing schedules in several ways. The precedence restrictions, which form part of the schedule building and the unintentional errors of scheduling two jobs on the same time in a machine are automatically taken care of by the system. The manual scheduling may be a bit cumbersome, but that is the price to be paid for the total flexibility it offers.

CONCLUSION

Schedulers have traditionally emphasised the importance of the bottleneck machines to draw up shop schedules. The basic objective of this is (1) to conceptualize the bottleneck in general flow shops and use the information to advantage in the scheduling decisions for the general flow shop problems and (2) to give a feel for the usefulness of the interactive scheduling in practical situations.

The superior performance of the heuristics using the focused approach have proved that the concept of bottleneck as visualised in this work is valid for general flow shops. The results of the experiments do show that the information on the bottleneck machines can be used to advantage in the solutions to the general flow shop scheduling problems. The usefulness of the interactive scheduling is brought out in the interactive computer system developed in this work. It helps to visualise how the much needed flexibility can be incorporated in the scheduling prodcedures to make them effective in pratical scheduling situations.

Though only the weighted tardiness criteria is tested in this work, the focused approach may be applicable to scheduling problems with objectives like minimising flow time, makespan and number of jobs tardy.

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APPENDICES

EFFECT OF JOBTYPES AND MACHINES(PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 50

HEURISTIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	
(1)	2.005*	0.086+	4	1.867*	0.002+	9	1.937*	0.016+	
(2)	2.029	0.109	1	2.065	0.199	0	2.023	0.103	
(3)	2.014	0.094	5	2.076	0.211	1	2.065	0.144	
(4)	2.073	0.154	1	2.187	0.322	0	2.053	0.132	
(5)	3.043	1.124	0	2.632	0.767	0	2.912	0.991	
(6)	3.228	1.309	0	2.895	1.030	0	2.869	0.948	
(1)	1.750*	0.000+	10	1.742*	0.003+	8	1.810*	0.000+	
(2)	1.898	0.148	0	1.836	0.096	0	1.909	0.099	
(3)	1.879	0.129	0	1.817	0.078	2	1.884	0.074	
(4)	1.922	0.171	0	1.847	0.107	0	1.884	0.074	
(5)	2.626	0.875	0	2.606	0.866	0	2.518	0.708	
(6)	2.968	1.217	0	2.788	1.048	0	2.791	0.981	
(1)	1.840*	0.002+	8	1.758*	0.000+	10	1.692*	0.000+	1
(2)	1.904	0.066	0	1.851	0.093	0	1.835	0.083	
(3)	1.887	0.049	3	1.818	0.060	0	1.820	0.060	
(4)	1.896	0.058	3	1.810	0.052	0	1.820	0.060	
(5)	2.934	1.097	0	2.527	0.770	0	2.497	0.787	
(6)	2.888	1.050	0	2.543	0.785	0	2.638	0.836	

1.1 :: FOR R=0.6,T=0.9 (SMALL RANGE, HIGH TARDINESS)

HEURISTIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2
(1)	0.426	0.066	1	0.477*	0.023+	9	0.513*	0.029+
(2)	0.393	0.034	4	0.648	0.193	0	0.573	0.089
(3)	0.378*	0.018+	6	0.599	0.144	1	0.559	0.076
(4)	0.424	0.065	1	0.625	0.171	0	0.561	0.077
(5)	0.842	0.483	0	0.892	0.438	0	1.014	0.530
(6)	1.273	0.914	0	1.275	0.820	0	1.154	0.671
(1)	0.484*	0.006+	8	0.534*	0.024+	2	0.527	0.043
(2)	0.582	0.105	2	0.537	0.027	4	0.521*	0.037+
(3)	0.559	0.082	0	0.547	0.037	4	0.560	0.077
(4)	0.577	0.100	0	0.618	0.107	0	0.560	0.077
(5)	0.888	0.411	0	1.064	0.554	0	0.917	0.434
(6)	1.389	0.911	0	1.309	0.798	0	1.243	0.759
(1)	0.457	0.053	3	0.592*	0.003+	8	0.532*	0.005+
(2)	0.579	0.175	3	0.628	0.038	3	0.537	0.042
(3)	0.438*	0.033+	5	0.652	0.062	0	0.572	0.068
(4)	0.444	0.039	3	0.645	0.055	0	0.572	0.068
(5)	0.925	0.521	0	1.065	0.475	0	0.830	0.525
(6)	1.302	0.897	0	1.167	0.577	0	1.352	0.875

1.2 :: FOR R=0.6,T=0.5 (SMALL RANGE, MEDIUM TARDINESS)

:FFECT OF JOBTYPES AND MACHINES (PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 50

.OF CS	HEURI-STIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
	(1)	0.010	0.010	1	0.026	0.023	1	0.007	0.004	4
	(2)	0.000*	0.000+	8	0.011	0.008	4	0.009	0.006	5
	(3)	0.000*	0.000+	8	0.013	0.009	1	0.005*	0.002+	5
	(4)	0.000*	0.000+	6	0.009	0.006	3	0.007	0.004	5
	(5)	0.001	0.001	9	0.005*	0.001+	6	0.014	0.011	4
	(6)	0.185	0.185	0	0.291	0.288	0	0.242	0.239	0
	(1)	0.074	0.067	0	0.110	0.075	0	0.079	0.071	0
	(2)	0.020	0.013	0	0.038*	0.003+	4	0.019	0.011	2
	(3)	0.009	0.002	2	0.055	0.019	4	0.012*	0.004+	8
	(4)	0.008*	0.001+	4	0.054	0.019	6	0.012*	0.004+	8
	(5)	0.049	0.042	6	0.085	0.050	0	0.024	0.016	0
	(6)	0.451	0.444	0	0.403	0.367	0	0.324	0.316	0
	(1)	0.050	0.045	0	0.114	0.070	0	0.081	0.072	1
	(2)	0.006*	0.000+	8	0.057*	0.014	5	0.022	0.016	1
	(3)	0.007	0.001	3	0.062	0.018	3	0.016*	0.014+	8
	(4)	0.007	0.001	5	0.057*	0.013+	3	0.016*	0.014+	8
	(5)	0.020	0.015	3	0.156	0.112	0	0.030	0.121	0
	(6)	0.289	0.283	0	0.305	0.262	0	0.321	0.273	0

ABLE 1.3 :: FOR R=0.6,T=0.1 (SMALL RANGE, LOW TARDINESS)

	(1)	2.010	0.117	3	1.823*	0.000+	10	1.873*	0.003+	9
	(2)	1.961*	0.069+	5	2.018	0.195	0	1.996	0.126	0
	(3)	2.004	0.112	1	2.049	0.226	0	2.070	0.200	0
	(4)	1.992	0.099	3	2.150	0.327	0	2.045	0.175	1
	(5)	2.875	0.983	0	2.554	0.731	0	2.785	0.915	0
	(6)	3.209	1.317	0	2.871	1.048	0	2.858	0.988	0
	(1)	1.727*	0.000+	10	1.709*	0.000+	10	1.803*	0.000+	10
	(2)	1.933	0.206	0	1.860	0.151	0	1.886	0.083	0
	(3)	1.851	0.125	0	1.824	0.116	0	1.872	0.068	0
	(4)	1.895	0.168	0	1.843	0.134	0	1.872	0.068	0
	(5)	2.608	0.881	0	2.575	0.866	0	2.660	0.857	0
	(6)	2.939	1.212	0	2.764	1.055	0	2.768	0.965	0
	(1)	1.825*	0.002+	5	1.762*	0.000+	10	1.828*	0.000+	10
	(2)	1.910	0.086	0	1.832	0.070	0	1.896	0.080	0
	(3)	1.839	0.015	5	1.815	0.053	0	1.875	0.064	0
	(4)	1.854	0.030	3	1.808	0.046	0	1.880	0.045	0
	(5)	2.745	0.922	0	2.440	0.678	0	2.525	0.428	0
	(6)	2.865	1.041	0	2.531	0.769	0	2.628	0.939	0

TABLE 1.4 :: FOR R=1.1,T=0.9 (MEDIUM RANGE, HIGH TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
5	(1)	0.010	0.010	1	0.026	0.023	1	0.007	0.004	
	(2)	0.000*	0.000+	8	0.011	0.008	4	0.009	0.006	
	(3)	0.000*	0.000+	8	0.013	0.009	1	0.005*	0.002+	
	(4)	0.000*	0.000+	6	0.009	0.006	3	0.007	0.004	
	(5)	0.001	0.001	9	0.005*	0.001+	6	0.014	0.011	
	(6)	0.185	0.185	0	0.291	0.288	0	0.242	0.239	
10	(1)	0.074	0.067	0	0.110	0.075	0	0.079	0.071	
	(2)	0.020	0.013	0	0.038*	0.003+	4	0.019	0.011	
	(3)	0.009	0.002	2	0.055	0.019	4	0.012*	0.004+	
	(4)	0.008*	0.001+	4	0.054	0.019	6	0.012*	0.004+	
	(5)	0.049	0.042	6	0.085	0.050	0	0.024	0.016	
	(6)	0.451	0.444	0	0.403	0.367	0	0.324	0.316	
15	(1)	0.050	0.045	0	0.114	0.070	0	0.081	0.072	
	(2)	0.006*	0.000+	8	0.057*	0.014	5	0.022	0.016	
	(3)	0.007	0.001	3	0.062	0.018	3	0.016*	0.014+	
	(4)	0.007	0.001	5	0.057*	0.013+	3	0.016*	0.014+	
	(5)	0.020	0.015	3	0.156	0.112	0	0.030	0.121	
	(6)	0.289	0.283	0	0.305	0.262	0	0.321	0.273	

TABLE 1.3 :: FOR R=0.6,T=0.1 (SMALL RANGE, LOW TARDINESS)

5	(1)	2.010	0.117	3	1.823*	0.000+	10	1.873*	0.003+
	(2)	1.961*	0.069+	5	2.018	0.195	0	1.996	0.126
	(3)	2.004	0.112	1	2.049	0.226	0	2.070	0.200
	(4)	1.992	0.099	3	2.150	0.327	0	2.045	0.175
	(5)	2.875	0.983	0	2.554	0.731	0	2.785	0.915
	(6)	3.209	1.317	0	2.871	1.048	0	2.858	0.988
10	(1)	1.727*	0.000+	10	1.709*	0.000+	10	1.803*	0.000+
	(2)	1.933	0.206	0	1.860	0.151	0	1.886	0.083
	(3)	1.851	0.125	0	1.824	0.116	0	1.872	0.068
	(4)	1.895	0.168	0	1.843	0.134	0	1.872	0.068
	(5)	2.608	0.881	0	2.575	0.866	0	2.660	0.857
	(6)	2.939	1.212	0	2.764	1.055	0	2.768	0.965
15	(1)	1.825*	0.002+	5	1.762*	0.000+	10	1.828*	0.000+
	(2)	1.910	0.086	0	1.832	0.070	0	1.896	0.080
	(3)	1.839	0.015	5	1.815	0.053	0	1.875	0.064
	(4)	1.854	0.030	3	1.808	0.046	0	1.880	0.045
	(5)	2.745	0.922	0	2.440	0.678	0	2.525	0.428
	(6)	2.865	1.041	0	2.531	0.769	0	2.628	0.939

TABLE 1.4 :: FOR R=1.1,T=0.9 (MEDIUM RANGE, HIGH TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (PROPORTIONAL JOB WEIGHTS). NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
5	(1)	0.427	0.172	0	0.440*	0.070+	4	0.372*	0.030+	
	(2)	0.275	0.019	5	0.508	0.138	1	0.406	0.064	
	(3)	0.271*	0.015+	5	0.448	0.078	3	0.429	0.087	
	(4)	0.284	0.029	1	0.463	0.093	4	0.425	0.083	
	(5)	0.677	0.422	0	0.674	0.304	0	0.803	0.461	
	(6)	1.306	1.051	0	1.197	0.827	0	1.144	0.802	
10	(1)	0.466	0.063	4	0.530	0.057	2	0.565	0.060	
	(2)	0.453	0.050	2	0.494	0.020	6	0.516*	0.010+	
	(3)	0.408*	0.005+	4	0.492*	0.019+	2	0.531	0.025	
	(4)	0.433	0.030	4	0.531	0.058	0	0.531	0.025	
	(5)	0.903	0.499	0	1.022	0.549	0	1.003	0.498	
	(6)	1.407	1.003	0	1.350	0.877	0	1.282	0.777	
15	(1)	0.515	0.150	0	0.595	0.051	3	0.585	0.062	
	(2)	0.414	0.049	3	0.557*	0.013+	5	0.504*	0.015+	
	(3)	0.396*	0.031+	8	0.612	0.068	0	0.581	0.073	
	(4)	0.396*	0.031+	8	0.604	0.060	3	0.532	0.058	
	(5)	1.040	0.676	0	1.225	0.681	0	1.023	0.732	
	(6)	1.310	0.946	0	1.221	0.677	0	1.323	0.787	

TABLE 1.5 :: FOR R=1.1,T=0.5 (MEDIUM RANGE, MEDIUM TARDINESS)

5	(1)	0.003	0.003	5	0.006	0.006	1	0.001	0.001	
	(2)	0.000*	0.000+	10	0.003	0.003	5	0.000*	0.000+	
	(3)	0.000*	0.000+	10	0.002	0.002	5	0.000*	0.000+	
	(4)	0.000*	0.000+	10	0.002	0.002	6	0.000*	0.000+	
	(5)	0.000*	0.000+	10	0.000*	0.000+	10	0.000*	0.000+	
	(6)	0.372	0.372	0	0.381	0.381	0	0.329	0.329	
10	(1)	0.098	0.098	0	0.135	0.135	0	0.081	0.081	
	(2)	0.000*	0.000+	8	0.002	0.002	6	0.000*	0.000+	
	(3)	0.002	0.002	8	0.003	0.003	2	0.000*	0.000+	
	(4)	0.004	0.004	4	0.002	0.002	4	0.000*	0.000+	
	(5)	0.000*	0.000+	10	0.000*	0.000+	10	0.000*	0.000+	
	(6)	0.449	0.449	0	0.568	0.568	0	0.379	0.379	
15	(1)	0.057	0.055	0	0.113	0.112	0	0.067	0.114	
	(2)	0.003	0.001	8	0.001*	0.000+	10	0.001*	0.000+	
	(3)	0.002*	0.000+	10	0.008	0.007	3	0.001*	0.000+	
	(4)	0.002*	0.000+	8	0.008	0.007	3	0.001*	0.000+	
	(5)	0.005	0.003	8	0.006	0.005	5	0.001*	0.000+	
	(6)	0.411	0.409	0	0.385	0.383	0	0.438	0.427	

TABLE 1.6 ::FOR R=1.1,T=0.1 (MEDIUM RANGE, LOW TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
	(1)	2.051	0.112	1	1.844*	0.006+	9	1.902*	0.020+	
	(2)	2.015*	0.077+	5	2.057	0.219	0	1.959	0.078	
	(3)	2.036	0.097	4	2.068	0.230	1	2.077	0.196	
5	(4)	2.074	0.135	0	2.163	0.325	0	2.069	0.188	
	(5)	2.921	0.983	0	2.713	0.875	0	2.826	0.945	
	(6)	3.242	1.303	0	2.881	1.043	0	2.874	0.993	
	(1)	1.753*	0.000+	10	1.755*	0.006+	6	1.803*	0.000+	
	(2)	2.008	0.255	0	1.816	0.067	2	1.927	0.124	
	(3)	1.869	0.116	0	1.832	0.083	2	1.906	0.103	
10	(4)	1.912	0.159	0	1.855	0.106	2	1.906	0.103	
	(5)	2.584	0.832	0	2.504	0.755	0	2.587	0.784	
	(6)	2.968	1.215	0	2.786	1.037	0	2.796	0.993	
	(1)	1.855*	0.002+	8	1.737*	0.000+	10	1.731*	0.000+	
	(2)	1.962	0.109	0	1.842	0.105	0	1.838	0.104	
15	(3)	1.895	0.043	3	1.812	0.076	0	1.804	0.076	
	(4)	1.911	0.058	3	1.807	0.071	0	1.804	0.076	
	(5)	2.788	0.935	0	2.663	0.927	0	2.532	0.936	
	(6)	2.899	1.047	0	2.544	0.807	0	2.542	0.947	

TABLE 1.7 :: FOR R=1.6,T=0.9 (LARGE RANGE, HIGH TARDINESS)

	(1)	0.352	0.125	0	0.395	0.063	5	0.378	0.028
	(2)	0.260	0.033	1	0.407	0.075	3	0.374*	0.024+
5	(3)	0.228*	0.001+	8	0.380*	0.048+	3	0.374*	0.024+
	(4)	0.258	0.031	3	0.386	0.054	1	0.390	0.040
	(5)	0.622	0.395	0	0.634	0.302	0	0.812	0.462
	(6)	1.309	1.083	0	1.232	0.900	0	1.302	0.952
	(1)	0.514	0.119	0	0.572	0.078	2	0.638	0.107
	(2)	0.437	0.041	2	0.545	0.051	2	0.537*	0.007+
10	(3)	0.399*	0.003+	8	0.528*	0.034+	6	0.597	0.067
	(4)	0.421	0.026	6	0.570	0.076	4	0.597	0.067
	(5)	0.819	0.424	0	0.969	0.474	0	0.960	0.429
	(6)	1.443	1.047	0	1.383	0.888	0	1.416	0.885
	(1)	0.588	0.106	0	0.728	0.074	0	0.737	0.081
	(2)	0.485*	0.003+	8	0.659*	0.004+	8	0.642*	0.006+
15	(3)	0.494	0.012	3	0.692	0.037	3	0.703	0.039
	(4)	0.513	0.031	0	0.694	0.039	0	0.703	0.039
	(5)	1.080	0.598	0	1.185	0.531	0	1.182	0.572
	(6)	1.300	0.818	0	1.349	0.694	0	1.439	0.325

TABLE 1.8 :: FOR R=1.6,T=0.5 (LARGE RANGE, MEDIUM TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (PROPORTIONAL JOB WEIGHTS)

NUMBER OF JOBS = 50

NO.OF M/CS	HEURISTIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
5	(1)	0.013	0.013	3	0.032	0.030	3	0.002	0.001	6
	(2)	0.001*	0.001	9	0.006	0.003	6	0.001*	0.000+	10
	(3)	0.001*	0.001	8	0.008	0.006	4	0.001*	0.000+	8
	(4)	0.001*	0.000+	10	0.008	0.005	5	0.001*	0.001	8
	(5)	0.002	0.002	9	0.003*	0.000+	9	0.002	0.002	8
	(6)	0.623	0.622	0	0.602	0.599	0	0.603	0.603	0
10	(1)	0.232	0.194	0	0.206	0.167	0	0.170	0.144	0
	(2)	0.045	0.007+	8	0.039*	0.000+	8	0.030*	0.004+	4
	(3)	0.044*	0.007+	6	0.071	0.032	0	0.034	0.008	0
	(4)	0.045	0.007+	4	0.071	0.032	0	0.034	0.008	0
	(5)	0.071	0.034	6	0.081	0.042	4	0.034	0.008	6
	(6)	0.727	0.690	0	0.722	0.683	0	0.680	0.654	0
15	(1)	0.128	0.111	0	0.176	0.142	0	0.182	0.153	0
	(2)	0.022	0.005	0	0.051	0.018	0	0.065	0.019	0
	(3)	0.018*	0.001+	5	0.034*	0.001+	8	0.042*	0.002+	8
	(4)	0.018*	0.001+	5	0.034*	0.001+	5	0.042*	0.002+	8
	(5)	0.028	0.010	8	0.055	0.021	3	0.062	0.015	6
	(6)	0.554	0.537	0	0.609	0.575	0	0.732	0.632	0

TABLE 1.9 :: FOR R=1.6,T=0.1 (LARGE RANGE, LOW TARDINESS)

M1: Normalised Average Weighted Tardiness
M2: Normalised Average Deviation From The Best
M3: Number Of Times Best Out Of 10
* : Minimum Value Of Normalised Average Weighted Tardiness
\+ : Minimum Value Of Normalised Average Deviation From The Best

EFFECT OF RANGE AND TARDINESS (PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 5Ø

RANGE	HEURISTIC	TARDINESS=Ø.9 M1	M2	M3	TARDINESS=Ø.5 M1	M2	M3	TARDINESS=Ø.1 M1	M2
	(1)	2.ØØ5*	Ø.Ø86+	4	Ø.426	Ø.Ø66	1	Ø.Ø1Ø	Ø.Ø1Ø
	(2)	2.Ø29	Ø.1Ø9	1	Ø.393	Ø.Ø34	4	Ø.ØØØ*	Ø.ØØØ+
	(3)	2.Ø14	Ø.Ø94	5	Ø.378*	Ø.Ø18+	6	Ø.ØØØ*	Ø.ØØØ+
Ø.6	(4)	2.Ø73	Ø.154	1	Ø.424	Ø.Ø65	1	Ø.ØØØ*	Ø.ØØØ+
	(5)	3.Ø43	1.124	Ø	Ø.842	Ø.483	Ø	Ø.ØØ1	Ø.ØØ1
	(6)	3.228	1.3Ø9	Ø	1.273	Ø.914	Ø	Ø.185	Ø.185
	(1)	2.Ø1Ø	Ø.117	3	Ø.427	Ø.172	Ø	Ø.ØØ3	Ø.ØØ3
	(2)	1.961*	Ø.Ø69+	5	Ø.275	Ø.Ø19	5	Ø.ØØØ*	Ø.ØØØ+
	(3)	2.ØØ4	Ø.112	1	Ø.271*	Ø.Ø15+	5	Ø.ØØØ*	Ø.ØØØ+
1.1	(4)	1.992	Ø.Ø99	3	Ø.284	Ø.Ø29	1	Ø.ØØØ*	Ø.ØØØ+
	(5)	2.875	Ø.983	Ø	Ø.677	Ø.422	Ø	Ø.ØØØ*	Ø.ØØØ+
	(6)	3.2Ø9	1.317	Ø	1.3Ø6	1.Ø51	Ø	Ø.372	Ø.372
	(1)	2.Ø51	Ø.112	1	Ø.352	Ø.125	Ø	Ø.Ø13	Ø.Ø13
	(2)	2.Ø15*	Ø.Ø77+	5	Ø.26Ø	Ø.Ø33	1	Ø.ØØ1*	Ø.ØØ1
	(3)	2.Ø36	Ø.Ø97	4	Ø.228*	Ø.ØØ1+	8	Ø.ØØ1*	Ø.ØØ1
	(4)	2.Ø74	Ø.135	Ø	Ø.258	Ø.Ø31	3	Ø.ØØ1*	Ø.ØØØ+
1.6	(5)	2.921	Ø.983	Ø	Ø.622	Ø.395	Ø	Ø.ØØ2	Ø.ØØ2
	(6)	3.242	1.3Ø3	Ø	1.3Ø9	1.Ø83	Ø	Ø.623	Ø.622

TABLE 2.1 :: FOR MACHINES = 5 , JOBTYPES= 7

	(1)	1.867*	Ø.ØØ2+	9	Ø.477*	Ø.Ø23+	9	Ø.Ø26	Ø.Ø23
	(2)	2.Ø65	Ø.199	Ø	Ø.648	Ø.193	Ø	Ø.Ø11	Ø.ØØ8
	(3)	2.Ø76	Ø.211	1	Ø.599	Ø.144	1	Ø.Ø13	Ø.ØØ9
Ø.6	(4)	2.187	Ø.322	Ø	Ø.625	Ø.171	Ø	Ø.ØØ9	Ø.ØØ6
	(5)	2.632	Ø.767	Ø	Ø.892	Ø.438	Ø	Ø.ØØ5*	Ø.ØØ1+
	(6)	2.895	1.Ø3Ø	Ø	1.275	Ø.82Ø	Ø	Ø.291	Ø.288
	(1)	1.823*	Ø.ØØØ+	1Ø	Ø.44Ø*	Ø.Ø7Ø+	4	Ø.ØØ6	Ø.ØØ6
	(2)	2.Ø18	Ø.195	Ø	Ø.5Ø8	Ø.138	1	Ø.ØØ3	Ø.ØØ3
	(3)	2.Ø49	Ø.226	Ø	Ø.448	Ø.Ø78	3	Ø.ØØ2	Ø.ØØ2
1.1	(4)	2.15Ø	Ø.327	Ø	Ø.463	Ø.Ø93	4	Ø.ØØ2	Ø.ØØ2
	(5)	2.554	Ø.731	Ø	Ø.674	Ø.3Ø4	Ø	Ø.ØØØ*	Ø.ØØØ+
	(6)	2.871	1.Ø48	Ø	1.197	Ø.827	Ø	Ø.381	Ø.381
	(1)	1.844*	Ø.ØØ6+	9	Ø.395	Ø.Ø63	5	Ø.Ø32	Ø.Ø3Ø
	(2)	2.Ø57	Ø.219	Ø	Ø.4Ø7	Ø.Ø75	3	Ø.ØØ6	Ø.ØØ3
	(3)	2.Ø68	Ø.23Ø	1	Ø.38Ø	Ø.Ø48	3	Ø.ØØ8	Ø.ØØ6
	(4)	2.163	Ø.325	Ø	Ø.386*	Ø.Ø54+	1	Ø.ØØ8	Ø.ØØ5
1.6	(5)	2.713	Ø.875	Ø	Ø.634	Ø.3Ø2	Ø	Ø.ØØ3*	Ø.ØØØ+
	(6)	2.881	1.Ø43	Ø	1.232	Ø.9ØØ	Ø	Ø.6Ø2	Ø.599

TABLE 2.2 :: FOR MACHINES = 5 , JOBTYPES= 15

EFFECT OF RANGE AND TARDINESS (PROPORTIONAL JOB WEIGHTS)

NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2	M3
	(1)	1.937*	0.016+	6	0.513*	0.029+	8	0.007	0.004	4
	(2)	2.023	0.103	1	0.573	0.089	0	0.009	0.006	5
	(3)	2.065	0.144	1	0.559	0.076	1	0.005*	0.002+	5
0.6	(4)	2.053	0.132	3	0.561	0.077	1	0.007	0.004	5
	(5)	2.912	0.991	0	1.014	0.530	0	0.014	0.011	4
	(6)	2.869	0.948	0	1.154	0.671	0	0.242	0.239	0
	(1)	1.873*	0.003+	9	0.372*	0.030+	6	0.001	0.001	8
	(2)	1.996	0.126	0	0.406	0.064	1	0.000*	0.000*	9
	(3)	2.070	0.200	0	0.429	0.087	1	0.000*	0.000*	9
1.1	(4)	2.045	0.175	1	0.425	0.083	1	0.000*	0.000*	10
	(5)	2.785	0.915	0	0.803	0.461	0	0.000*	0.000*	10
	(6)	2.858	0.988	0	1.144	0.802	0	0.329	0.329	0
	(1)	1.902*	0.020+	6	0.378	0.028	6	0.002	0.001	6
	(2)	1.959	0.078	4	0.374*	0.024+	3	0.001*	0.000+	10
	(3)	2.077	0.196	0	0.374*	0.024+	1	0.001*	0.000+	8
	(4)	2.069	0.188	1	0.390	0.040	0	0.001*	0.001	8
1.6	(5)	2.826	0.945	0	0.812	0.462	0	0.002	0.002	8
	(6)	2.874	0.993	0	1.302	0.952	0	0.603	0.603	0

TABLE 2.3 :: FOR MACHINES = 5 , JOBTYPES= 50

	(1)	1.750*	0.000+	10	0.484*	0.006+	8	0.074	0.067
	(2)	1.898	0.148	0	0.582	0.105	2	0.020	0.013
	(3)	1.879	0.129	0	0.559	0.082	0	0.009	0.002
0.6	(4)	1.922	0.171	0	0.577	0.100	0	0.008*	0.001+
	(5)	2.626	0.875	0	0.888	0.411	0	0.049	0.042
	(6)	2.968	1.217	0	1.389	0.911	0	0.451	0.444
	(1)	1.727*	0.000+	10	0.466	0.063	4	0.098	0.098
	(2)	1.933	0.206	0	0.453	0.050	2	0.000*	0.000+
	(3)	1.851	0.125	0	0.408*	0.005+	4	0.002	0.002
1.1	(4)	1.895	0.168	0	0.433	0.030	4	0.004	0.004
	(5)	2.608	0.881	0	0.903	0.499	0	0.000*	0.000+
	(6)	2.939	1.212	0	1.407	1.003	0	0.449	0.449
	(1)	1.753*	0.000+	10	0.514	0.119	0	0.232	0.194
	(2)	2.008	0.255	0	0.437	0.041	2	0.045	0.007+
	(3)	1.869	0.116	0	0.399*	0.003+	8	0.044*	0.007+
	(4)	1.912	0.159	0	0.421	0.026	6	0.045	0.007+
1.6	(5)	2.584	0.832	0	0.819	0.424	0	0.071	0.034
	(6)	2.968	1.215	0	1.443	1.047	0	0.727	0.690

TABLE 2.4 :: FOR MACHINES = 10 , JOBTYPES= 7

EFFECT OF RANGE AND TARDINESS (PROPORTIONAL JOB WEIGHTS) . NUMBER OF JOBS = 50

RANGE	HEURI-STIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2
	(1)	1.742*	0.003+	8	0.534*	0.024+	2	0.110	0.075
	(2)	1.836	0.096	0	0.537	0.027	4	0.038*	0.003+
	(3)	1.817	0.078	2	0.547	0.037	4	0.055	0.019
0.6	(4)	1.847	0.107	0	0.618	0.107	0	0.054	0.019
	(5)	2.606	0.866	0	1.064	0.554	0	0.085	0.050
	(6)	2.788	1.048	0	1.309	0.798	0	0.403	0.367
	(1)	1.709*	0.000+	10	0.530	0.057	2	0.135	0.135
	(2)	1.860	0.151	0	0.494	0.020	6	0.002	0.002
	(3)	1.824	0.116	0	0.492*	0.019+	2	0.003	0.003
1.1	(4)	1.843	0.134	0	0.531	0.058	0	0.002	0.002
	(5)	2.575	0.866	0	1.022	0.549	0	0.000*	0.000+
	(6)	2.764	1.055	0	1.350	0.877	0	0.568	0.568
	(1)	1.755*	0.006+	6	0.572	0.078	2	0.206	0.167
	(2)	1.816	0.067	2	0.545	0.051	2	0.039*	0.000+
	(3)	1.832	0.083	2	0.528*	0.034+	6	0.071	0.032
	(4)	1.855	0.106	2	0.570	0.076	4	0.071	0.032
1.6	(5)	2.504	0.755	0	0.969	0.474	0	0.081	0.042
	(6)	2.786	1.037	0	1.383	0.888	0	0.722	0.683

TABLE 2.5 :: FOR MACHINES = 10, JOBTYPES= 15

	(1)	1.810*	0.000+	10	0.527	0.043	2	0.079	0.071
	(2)	1.909	0.099	0	0.521*	0.037+	4	0.019	0.011
	(3)	1.884	0.074	0	0.560	0.077	4	0.012*	0.004+
0.6	(4)	1.884	0.074	0	0.560	0.077	4	0.012*	0.004+
	(5)	2.518	0.708	0	0.917	0.434	0	0.024	0.016
	(6)	2.791	0.981	0	1.243	0.759	0	0.324	0.316
	(1)	1.803*	0.000+	10	0.565	0.060	2	0.081	0.081
	(2)	1.886	0.083	0	0.516*	0.010+	6	0.000*	0.000*
	(3)	1.872	0.068	0	0.531	0.025	2	0.000*	0.000*
1.1	(4)	1.872	0.068	0	0.531	0.025	2	0.000*	0.000*
	(5)	2.660	0.857	0	1.003	0.498	0	0.000*	0.000*
	(6)	2.768	0.965	0	1.282	0.777	0	0.379	0.379
	(1)	1.803*	0.000+	10	0.638	0.107	0	0.170	0.144
	(2)	1.927	0.124	0	0.537*	0.007+	8	0.030*	0.004+
	(3)	1.906	0.103	0	0.597	0.067	2	0.034	0.008
	(4)	1.906	0.103	0	0.597	0.067	2	0.034	0.008
1.6	(5)	2.587	0.784	0	0.960	0.429	0	0.034	0.008
	(6)	2.796	0.993	0	1.416	0.885	0	0.680	0.654

TABLE 2.6 :: FOR MACHINES = 10, JOBTYPES= 50

EFFECT OF RANGE AND TARDINESS (PROPORTIONAL JOB WEIGHTS)
NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2
	(1)	1.840*	0.002+	8	0.457	0.053	3	0.050	0.045
	(2)	1.904	0.066	0	0.579	0.175	3	0.006*	0.000+
	(3)	1.887	0.049	3	0.438*	0.033+	5	0.007	0.001
0.6	(4)	1.896	0.058	3	0.444	0.039	3	0.007	0.001
	(5)	2.934	1.097	0	0.925	0.521	0	0.020	0.015
	(6)	2.888	1.050	0	1.302	0.897	0	0.289	0.283
	(1)	1.825*	0.002+	5	0.515	0.150	0	0.057	0.055
	(2)	1.910	0.086	0	0.414	0.049	3	0.003	0.001
	(3)	1.839	0.015	5	0.396*	0.031+	8	0.002*	0.000+
1.1	(4)	1.854	0.030	3	0.396*	0.031+	8	0.002*	0.000+
	(5)	2.745	0.922	0	1.040	0.676	0	0.005	0.003
	(6)	2.865	1.041	0	1.310	0.946	0	0.411	0.409
	(1)	1.855*	0.002+	8	0.588	0.106	0	0.128	0.111
	(2)	1.962	0.109	0	0.485*	0.003+	8	0.022	0.005
	(3)	1.895	0.043	3	0.494	0.012	3	0.018*	0.001+
	(4)	1.911	0.058	3	0.513	0.031	0	0.018*	0.001+
1.6	(5)	2.788	0.935	0	1.080	0.598	0	0.028	0.010
	(6)	2.899	1.047	0	1.300	0.818	0	0.554	0.537

TABLE 2.7 :: FOR MACHINES = 15, JOBTYPES= 7

RANGE	HEURISTIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2
	(1)	1.758*	0.000+	10	0.592*	0.003+	8	0.114	0.070
	(2)	1.851	0.093	0	0.628	0.038	3	0.057*	0.014
	(3)	1.818	0.060	0	0.652	0.062	0	0.062	0.018
0.6	(4)	1.810	0.052	0	0.645	0.055	0	0.057*	0.013+
	(5)	2.527	0.770	0	1.065	0.475	0	0.156	0.112
	(6)	2.543	0.785	0	1.167	0.577	0	0.305	0.262
	(1)	1.762*	0.000+	10	0.595	0.051	3	0.113	0.112
	(2)	1.832	0.070	0	0.557*	0.013+	5	0.001*	0.000+
	(3)	1.815	0.053	0	0.612	0.068	0	0.008	0.007
1.1	(4)	1.808	0.046	0	0.604	0.060	3	0.008	0.007
	(5)	2.440	0.678	0	1.225	0.681	0	0.006	0.005
	(6)	2.531	0.769	0	1.221	0.677	0	0.385	0.383
	(1)	1.737*	0.000+	10	0.728	0.074	0	0.176	0.142
	(2)	1.842	0.105	0	0.659*	0.004	8	0.051	0.018
	(3)	1.812	0.076	0	0.692	0.037+	3	0.034*	0.001+
	(4)	1.807	0.071	0	0.694	0.039	0	0.034*	0.001+
1.6	(5)	2.663	0.927	0	1.185	0.531	0	0.055	0.021
	(6)	2.544	0.807	0	1.349	0.694	0	0.609	0.575

TABLE 2.8 :: FOR MACHINES = 15 , JOBTYPES= 15

EFFECT OF RANGE AND TARDINESS (PROPORTIONAL JOB WEIGHTS)

NUMBER OF JOBS = 5Ø

RANGE	HEURISTIC	TARDINESS=Ø.9 M1	TARDINESS=Ø.9 M2	TARDINESS=Ø.9 M3	TARDINESS=Ø.5 M1	TARDINESS=Ø.5 M2	TARDINESS=Ø.5 M3	TARDINESS=Ø.1 M1	TARDINESS=Ø.1 M2
	(1)	1.692*	Ø.ØØØ+	1Ø	Ø.532*	Ø.ØØ5+	8	Ø.Ø81	Ø.Ø72
	(2)	1.835	Ø.Ø83	Ø	Ø.537	Ø.Ø42	3	Ø.Ø22	Ø.Ø16
	(3)	1.82Ø	Ø.Ø6Ø	Ø	Ø.572	Ø.Ø68	1	Ø.Ø16*	Ø.Ø14+
Ø.6	(4)	1.82Ø	Ø.Ø6Ø	Ø	Ø.572	Ø.Ø68	1	Ø.Ø16*	Ø.Ø14+
	(5)	2.497	Ø.787	Ø	Ø.83Ø	Ø.525	Ø	Ø.Ø3Ø	Ø.121
	(6)	2.638	Ø.836	Ø	1.352	Ø.875	Ø	Ø.321	Ø.273
	(1)	1.828*	Ø.ØØØ+	1Ø	Ø.585	Ø.Ø62	4	Ø.Ø67	Ø.114
	(2)	1.896	Ø.Ø8Ø	Ø	Ø.5Ø4*	Ø.Ø15+	8	Ø.ØØ1*	Ø.ØØØ+
	(3)	1.875	Ø.Ø64	Ø	Ø.581	Ø.Ø73	Ø	Ø.ØØ1*	Ø.ØØØ+
1.1	(4)	1.88Ø	Ø.Ø45	Ø	Ø.532	Ø.Ø58	4	Ø.ØØ1*	Ø.ØØØ+
	(5)	2.525	Ø.428	Ø	1.Ø23	Ø.732	Ø	Ø.ØØ1*	Ø.ØØØ+
	(6)	2.628	Ø.939	Ø	1.323	Ø.787	Ø	Ø.438	Ø.427
	(1)	1.731*	Ø.ØØØ+	1Ø	Ø.737	Ø.Ø81	Ø	Ø.182	Ø.153
	(2)	1.838	Ø.1Ø4	Ø	Ø.642*	Ø.ØØ6+	8	Ø.Ø65	Ø.Ø19
	(3)	1.8Ø4	Ø.Ø76	Ø	Ø.7Ø3	Ø.Ø39	3	Ø.Ø42*	Ø.ØØ2+
	(4)	1.8Ø4	Ø.Ø76	Ø	Ø.7Ø3	Ø.Ø39	3	Ø.Ø42*	Ø.ØØ2+
1.6	(5)	2.532	Ø.936	Ø	1.182	Ø.572	Ø	Ø.Ø62	Ø.Ø15
	(6)	2.542	Ø.947	Ø	1.439	Ø.325	Ø	Ø.732	Ø.632

TABLE 2.9 :: FOR MACHINES = 15 , JOBTYPES= 5Ø

M1: Normalised Average Weighted Tardiness
M2: Normalised Average Deviation From The Best
M3: Number Of Times Best Out Of 1Ø
* : Minimum Value Of Normalised Average Weighted Tardiness
+ : Minimum Value Of Normalised Average Deviation From The Best

EFFECT OF JOBTYPES AND MACHINES(EQUAL JOB WEIGHTS)

NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	JOBTYPES=7 M2	JOBTYPES=7 M3	JOBTYPES=15 M1	JOBTYPES=15 M2	JOBTYPES=15 M3	JOBTYPES=50 M1	JOBTYPES=50 M2	JOBTYPES=50 M3
5	(1)	2.059*	0.031+	6	2.035*	0.047+	2	2.037*	0.015+	8
	(2)	2.188	0.160	4	2.141	0.153	0	2.205	0.184	0
	(3)	2.235	0.207	4	2.024	0.036	6	2.140	0.118	2
	(4)	2.233	0.205	4	2.092	0.105	2	2.155	0.134	0
	(5)	3.296	1.268	0	2.862	0.874	0	3.144	1.123	0
	(6)	2.358	0.330	0	2.486	0.499	0	2.167	0.146	0
10	(1)	1.830*	0.000+	10	1.810*	0.000+	10	1.906*	0.005+	8
	(2)	1.980	0.150	0	2.023	0.213	0	1.995	0.093	2
	(3)	1.994	0.164	0	1.977	0.167	0	2.000	0.099	2
	(4)	2.043	0.213	0	1.975	0.165	0	2.000	0.099	2
	(5)	3.143	1.313	0	3.175	1.366	0	2.961	1.059	0
	(6)	2.378	0.548	0	2.272	0.462	0	2.264	0.363	0
15	(1)	1.957*	0.014+	8	1.778*	0.000+	10	1.699*	0.000+	10
	(2)	2.106	0.164	0	1.928	0.150	0	2.001	0.302	0
	(3)	1.997	0.054	0	1.958	0.180	0	1.820	0.120	0
	(4)	1.997	0.054	0	1.959	0.181	0	1.820	0.120	0
	(5)	3.352	1.409	0	3.010	1.233	0	2.921	1.222	0
	(6)	2.181	0.239	2	1.997	0.219	0	2.068	0.368	0

TABLE 3.1 :: FOR R=0.6,T=0.9 (SMALL RANGE, HIGH TARDINESS)

NUMBER OF JOBS = 50

5	(1)	0.540*	0.030+	6	0.639	0.096	2	0.550*	0.005+
	(2)	0.567	0.057	2	0.618*	0.075+	4	0.654	0.109
	(3)	0.566	0.055	4	0.595	0.053	4	0.650	0.104
	(4)	0.579	0.068	2	0.618	0.076	0	0.660	0.115
	(5)	0.946	0.436	0	0.962	0.419	0	1.025	0.480
	(6)	0.642	0.132	0	0.897	0.354	0	0.658	0.113
10	(1)	0.554*	0.026+	6	0.589*	0.005+	8	0.610*	0.020+
	(2)	0.656	0.127	4	0.670	0.087	0	0.654	0.064
	(3)	0.668	0.140	0	0.648	0.065	2	0.697	0.107
	(4)	0.705	0.176	0	0.659	0.075	0	0.697	0.107
	(5)	1.121	0.592	0	1.153	0.570	0	1.131	0.541
	(6)	0.867	0.338	0	0.849	0.265	0	0.814	0.225
15	(1)	0.621*	0.046*	4	0.611*	0.001+	6	0.607*	0.000+
	(2)	0.668	0.092	0	0.815	0.204	2	0.737	0.130
	(3)	0.622	0.046	4	0.731	0.121	0	0.690	0.083
	(4)	0.622	0.046	4	0.739	0.129	0	0.690	0.083
	(5)	1.086	0.511	0	1.223	0.613	0	1.304	0.698
	(6)	0.652	0.077	2	0.697	0.087	2	0.776	0.169

TABLE 3.2 :: FOR R=0.6,T=0.5 (SMALL RANGE, MEDIUM TARDINESS)

EFFECT OF JOBTYPES AND MACHINES(EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 5Ø

NO.OF M/CS	HEURISTIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=5Ø M1	M2	M3
5	(1)	Ø.Ø24	Ø.Ø23	2	Ø.Ø19	Ø.Ø18	4	Ø.Ø15	Ø.Ø15	
	(2)	Ø.ØØ1*	Ø.ØØØ+	1Ø	Ø.ØØ4*	Ø.ØØ3+	8	Ø.ØØØ*	Ø.ØØØ+	
	(3)	Ø.ØØ2	Ø.ØØ1	8	Ø.ØØ6	Ø.ØØ5	6	Ø.Ø13	Ø.Ø13	
	(4)	Ø.ØØ2	Ø.ØØ1	8	Ø.ØØ5	Ø.ØØ5	6	Ø.Ø14	Ø.Ø14	
	(5)	Ø.ØØ2	Ø.ØØ1	8	Ø.ØØ8	Ø.ØØ8	8	Ø.ØØ1	Ø.ØØ1	
	(6)	Ø.Ø72	Ø.Ø71	Ø	Ø.15Ø	Ø.149	Ø	Ø.1ØØ	Ø.1ØØ	
10	(1)	Ø.Ø95	Ø.Ø9Ø	Ø	Ø.1Ø4	Ø.Ø79	Ø	Ø.Ø82	Ø.Ø69	
	(2)	Ø.ØØ9*	Ø.ØØ5+	4	Ø.Ø29*	Ø.ØØ4+	6	Ø.Ø14*	Ø.ØØ2+	
	(3)	Ø.Ø17	Ø.Ø12	4	Ø.Ø31	Ø.ØØ6	2	Ø.Ø22	Ø.ØØ9	
	(4)	Ø.Ø11	Ø.ØØ6	6	Ø.Ø29*	Ø.ØØ4+	2	Ø.Ø19	Ø.ØØ6	
	(5)	Ø.ØØ6	Ø.ØØ1	8	Ø.Ø66	Ø.Ø41	2	Ø.Ø26	Ø.Ø14	
	(6)	Ø.238	Ø.233	Ø	Ø.213	Ø.188	Ø	Ø.187	Ø.175	
15	(1)	Ø.Ø75	Ø.Ø75	Ø	Ø.118	Ø.Ø81	Ø	Ø.158	Ø.Ø76	
	(2)	Ø.ØØØ*	Ø.ØØØ*	1Ø	Ø.Ø39*	Ø.ØØ2+	6	Ø.Ø93	Ø.Ø11	
	(3)	Ø.ØØØ*	Ø.ØØØ*	8	Ø.Ø5Ø	Ø.Ø13	Ø	Ø.Ø94	Ø.Ø12	
	(4)	Ø.ØØØ*	Ø.ØØØ*	8	Ø.Ø48	Ø.Ø11	2	Ø.Ø94	Ø.Ø12	
	(5)	Ø.ØØ7	Ø.ØØ7	8	Ø.Ø61	Ø.Ø24	2	Ø.16Ø	Ø.Ø77	
	(6)	Ø.Ø97	Ø.Ø97	Ø	Ø.167	Ø.13Ø	Ø	Ø.2Ø1	Ø.118	

TABLE 3.3 :: FOR R=Ø.6,T=Ø.1 (SMALL RANGE, LOW TARDINESS)

NO.OF M/CS	HEURISTIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=5Ø M1	M2	M3
5	(1)	2.Ø26*	Ø.Ø29+	4	2.ØØ4*	Ø.Ø55+	4	2.Ø28*	Ø.Ø2Ø*	
	(2)	2.13Ø	Ø.133	6	2.254	Ø.3Ø6	2	2.18Ø	Ø.172	
	(3)	2.137	Ø.14Ø	4	1.998	Ø.Ø49	4	2.119	Ø.111	
	(4)	2.116	Ø.119	6	2.11Ø	Ø.161	Ø	2.13Ø	Ø.122	
	(5)	3.129	1.132	Ø	2.971	1.Ø22	Ø	3.287	1.279	
	(6)	2.337	Ø.34Ø	Ø	2.465	Ø.516	Ø	2.142	Ø.133	
10	(1)	1.815*	Ø.ØØØ+	1Ø	1.794*	Ø.ØØØ+	1Ø	1.892*	Ø.ØØ3+	
	(2)	1.98Ø	Ø.165	Ø	2.Ø15	Ø.22Ø	Ø	1.993	Ø.1Ø4	
	(3)	1.963	Ø.148	Ø	1.954	Ø.16Ø	Ø	1.975	Ø.Ø86	
	(4)	2.Ø1Ø	Ø.195	Ø	1.947	Ø.153	Ø	1.975	Ø.Ø86	
	(5)	3.111	1.296	Ø	3.Ø24	1.229	Ø	2.966	1.Ø77	
	(6)	2.359	Ø.544	Ø	2.254	Ø.46Ø	Ø	2.245	Ø.356	
15	(1)	1.944*	Ø.Ø14+	8	1.779*	Ø.ØØØ+	1Ø	1.693*	Ø.ØØØ+	
	(2)	2.Ø89	Ø.159	Ø	1.962	Ø.183	Ø	2.Ø5Ø	Ø.357	
	(3)	1.984	Ø.Ø54	Ø	1.933	Ø.155	Ø	1.8Ø5	Ø.113	
	(4)	1.984	Ø.Ø54	Ø	1.942	Ø.163	Ø	1.8Ø5	Ø.113	
	(5)	3.267	1.338	Ø	2.982	1.2Ø3	Ø	2.982	1.289	
	(6)	2.162	Ø.232	2	1.976	Ø.198	Ø	2.Ø5Ø	Ø.357	

TABLE 3.4 :: FOR R=1.1,T=Ø.9 (MEDIUM RANGE, HIGH TARDINESS)

EFFECT OF JOBTYPES AND MACHINES(EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	JOBTYPES=7 M2	JOBTYPES=7 M3	JOBTYPES=15 M1	JOBTYPES=15 M2	JOBTYPES=15 M3	JOBTYPES=50 M1	JOBTYPES=50 M2
5	(1)	0.024	0.023	2	0.019	0.018	4	0.015	0.015
	(2)	0.001*	0.000+	10	0.004*	0.003+	8	0.000*	0.000+
	(3)	0.002	0.001	8	0.006	0.005	6	0.013	0.013
	(4)	0.002	0.001	8	0.005	0.005	6	0.014	0.014
	(5)	0.002	0.001	8	0.008	0.008	8	0.001	0.001
	(6)	0.072	0.071	0	0.150	0.149	0	0.100	0.100
10	(1)	0.095	0.090	0	0.104	0.079	0	0.082	0.069
	(2)	0.009*	0.005+	4	0.029*	0.004+	6	0.014*	0.002+
	(3)	0.017	0.012	4	0.031	0.006	2	0.022	0.009
	(4)	0.011	0.006	6	0.029*	0.004+	2	0.019	0.006
	(5)	0.006	0.001	8	0.066	0.041	2	0.026	0.014
	(6)	0.238	0.233	0	0.213	0.188	0	0.187	0.175
15	(1)	0.075	0.075	0	0.118	0.081	0	0.158	0.076
	(2)	0.000*	0.000*	10	0.039*	0.002+	6	0.093	0.011
	(3)	0.000*	0.000*	8	0.050	0.013	0	0.094	0.012
	(4)	0.000*	0.000*	8	0.048	0.011	2	0.094	0.012
	(5)	0.007	0.007	8	0.061	0.024	2	0.160	0.077
	(6)	0.097	0.097	0	0.167	0.130	0	0.201	0.118

TABLE 3.3 :: FOR R=0.6,T=0.1 (SMALL RANGE, LOW TARDINESS)

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	JOBTYPES=7 M2	JOBTYPES=7 M3	JOBTYPES=15 M1	JOBTYPES=15 M2	JOBTYPES=15 M3	JOBTYPES=50 M1	JOBTYPES=50 M2
5	(1)	2.026*	0.029+	4	2.004*	0.055+	4	2.028*	0.020*
	(2)	2.130	0.133	6	2.254	0.306	2	2.180	0.172
	(3)	2.137	0.140	4	1.998	0.049	4	2.119	0.111
	(4)	2.116	0.119	6	2.110	0.161	0	2.130	0.122
	(5)	3.129	1.132	0	2.971	1.022	0	3.287	1.279
	(6)	2.337	0.340	0	2.465	0.516	0	2.142	0.133
10	(1)	1.815*	0.000+	10	1.794*	0.000+	10	1.892*	0.003+
	(2)	1.980	0.165	0	2.015	0.220	0	1.993	0.104
	(3)	1.963	0.148	0	1.954	0.160	0	1.975	0.086
	(4)	2.010	0.195	0	1.947	0.153	0	1.975	0.086
	(5)	3.111	1.296	0	3.024	1.229	0	2.966	1.077
	(6)	2.359	0.544	0	2.254	0.460	0	2.245	0.356
15	(1)	1.944*	0.014+	8	1.779*	0.000+	10	1.693*	0.000+
	(2)	2.089	0.159	0	1.962	0.183	0	2.050	0.357
	(3)	1.984	0.054	0	1.933	0.155	0	1.805	0.113
	(4)	1.984	0.054	0	1.942	0.163	0	1.805	0.113
	(5)	3.267	1.338	0	2.982	1.203	0	2.982	1.289
	(6)	2.162	0.232	2	1.976	0.198	0	2.050	0.357

TABLE 3.4 :: FOR R=1.1,T=0.9 (MEDIUM RANGE, HIGH TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	JOBTYPES=7 M2	JOBTYPES=7 M3	JOBTYPES=15 M1	JOBTYPES=15 M2	JOBTYPES=15 M3	JOBTYPES=50 M1	JOBTYPES=50 M2	JOBTYPES=50 M3
	(1)	0.558	0.092	2	0.505	0.082	4	0.488	0.013	8
	(2)	0.480	0.015	6	0.559	0.137	0	0.535	0.059	2
	(3)	0.534	0.069	4	0.457	0.034	6	0.547	0.072	0
5	(4)	0.538	0.072	2	0.551	0.129	0	0.554	0.078	0
	(5)	0.825	0.359	0	0.648	0.226	0	0.913	0.437	0
	(6)	0.729	0.264	0	0.921	0.499	0	0.722	0.246	0
	(1)	0.576	0.052	4	0.575	0.011	6	0.622	0.060	4
	(2)	0.604	0.080	2	0.615	0.051	2	0.614	0.051	6
	(3)	0.617	0.093	4	0.614	0.049	2	0.588	0.026	0
10	(4)	0.626	0.102	2	0.626	0.062	0	0.588	0.026	0
	(5)	1.009	0.485	0	0.970	0.406	0	1.079	0.517	0
	(6)	0.936	0.412	0	0.866	0.301	0	0.866	0.304	0
	(1)	0.618	0.115	0	0.628	0.023	6	0.632	0.016	6
	(2)	0.538	0.035	6	0.686	0.081	2	0.741	0.125	2
	(3)	0.547	0.045	4	0.635	0.030	2	0.655	0.039	2
15	(4)	0.547	0.045	4	0.641	0.036	2	0.655	0.039	2
	(5)	0.926	0.423	0	1.285	0.680	0	1.191	0.575	0
	(6)	0.680	0.177	2	0.739	0.134	0	0.814	0.198	0

TABLE 3.5 :: FOR R=1.1,T=0.5 (MEDIUM RANGE, MEDIUM TARDINESS)

	(1)	0.013	0.013	6	0.009	0.009	8	0.000	0.000	8
	(2)	0.000	0.000	10	0.000	0.000	10	0.000	0.000	10
	(3)	0.000	0.000	10	0.000	0.000	10	0.000	0.000	10
5	(4)	0.000	0.000	10	0.000	0.000	10	0.000	0.000	10
	(5)	0.000	0.000	10	0.000	0.000	10	0.000	0.000	10
	(6)	0.169	0.169	0	0.305	0.305	0	0.178	0.178	0
	(1)	0.113	0.113	0	0.119	0.119	0	0.094	0.094	0
	(2)	0.000	0.000	10	0.002	0.002	8	0.000	0.000	10
	(3)	0.002	0.002	8	0.005	0.005	8	0.000	0.000	10
10	(4)	0.000	0.000	10	0.005	0.005	8	0.000	0.000	10
	(5)	0.000	0.000	10	0.000	0.000	10	0.000	0.000	10
	(6)	0.270	0.270	0	0.272	0.272	0	0.260	0.260	0
	(1)	0.109	0.109	0	0.125	0.125	0	0.143	0.141	
	(2)	0.000	0.000	10	0.011	0.010	6	0.017	0.016	4
	(3)	0.001	0.001	6	0.003	0.002	6	0.011	0.010	2
15	(4)	0.001	0.001	6	0.002	0.001	8	0.011	0.010	2
	(5)	0.000	0.000	10	0.007	0.006	6	0.007	0.005	4
	(6)	0.189	0.189	0	0.199	0.198	0	0.247	0.246	0

TABLE 3.6 ::FOR R=1.1,T=0.1 (MEDIUM RANGE, LOW TARDINESS)

NUMBER OF JOBS = 50

NO.OF M/CS	HEURI-STIC	JOBTYPES=7 M1	M2	M3	JOBTYPES=15 M1	M2	M3	JOBTYPES=50 M1	M2	M3
	(1)	2.079	0.034	2	1.986	0.045	6	2.037	0.015	8
	(2)	2.130	0.085	8	2.096	0.155	0	2.205	0.183	0
	(3)	2.267	0.221	4	2.024	0.083	2	2.144	0.121	2
5	(4)	2.249	0.204	6	2.071	0.130	2	2.159	0.137	0
	(5)	3.122	1.077	0	2.914	0.973	0	3.162	1.139	0
	(6)	2.357	0.311	0	2.476	0.535	0	2.175	0.153	0
	(1)	1.829	0.000	10	1.815	0.000	10	1.926	0.010	8
	(2)	1.992	0.163	0	2.058	0.242	0	2.096	0.180	0
	(3)	1.974	0.145	0	1.974	0.159	0	2.011	0.094	2
10	(4)	2.027	0.198	0	1.971	0.156	0	2.011	0.094	2
	(5)	3.031	1.202	0	2.909	1.094	0	3.057	1.140	0
	(6)	2.381	0.552	0	2.267	0.452	0	2.268	0.352	0
	(1)	1.977	0.016	6	1.796	0.000	10	1.706	0.000	10
	(2)	2.190	0.229	0	2.001	0.205	0	2.161	0.454	0
	(3)	2.005	0.045	2	1.972	0.176	0	1.826	0.120	0
15	(4)	2.005	0.045	2	1.980	0.184	0	1.824	0.118	0
	(5)	3.342	1.381	0	3.069	1.273	0	2.960	1.254	0
	(6)	2.179	0.218	2	2.002	0.206	0	2.067	0.360	0

TABLE 3.7 :: FOR R=1.6,T=0.9 (LARGE RANGE, HIGH TARDINESS)

	(1)	0.594	0.181	0	0.480	0.046	2	0.506	0.043	2
	(2)	0.422	0.009	8	0.523	0.089	2	0.472	0.008	8
	(3)	0.456	0.042	4	0.473	0.039	6	0.537	0.073	0
5	(4)	0.462	0.048	4	0.623	0.189	0	0.539	0.075	0
	(5)	0.663	0.249	0	0.885	0.451	0	0.860	0.397	0
	(6)	0.816	0.403	0	1.003	0.569	0	0.787	0.324	0
	(1)	0.535	0.055	4	0.610	0.052	4	0.667	0.145	0
	(2)	0.490	0.010	2	0.608	0.050	4	0.534	0.011	4
	(3)	0.523	0.043	4	0.611	0.053	2	0.538	0.016	6
10	(4)	0.543	0.064	0	0.633	0.075	0	0.549	0.027	4
	(5)	0.746	0.267	0	1.063	0.506	0	0.978	0.456	0
	(6)	0.971	0.492	0	0.937	0.379	0	0.892	0.370	0
	(1)	0.698	0.187	0	0.703	0.072	2	0.695	0.023	4
	(2)	0.523	0.012	8	0.653	0.022	6	0.765	0.093	2
	(3)	0.548	0.037	2	0.655	0.024	0	0.699	0.027	4
15	(4)	0.548	0.037	2	0.670	0.040	2	0.699	0.027	4
	(5)	1.000	0.489	0	1.293	0.663	0	1.293	0.621	0
	(6)	0.764	0.253	0	0.820	0.190	0	0.898	0.226	0

TABLE 3.8 :: FOR R=1.6,T=0.5 (LARGE RANGE, MEDIUM TARDINESS)

EFFECT OF JOBTYPES AND MACHINES (EQUAL JOB WEIGHTS)

NUMBER OF JOBS = 50

NO. OF M/CS	HEURI-STIC	JOBTYPES=7 M1	JOBTYPES=7 M2	JOBTYPES=7 M3	JOBTYPES=15 M1	JOBTYPES=15 M2	JOBTYPES=15 M3	JOBTYPES=50 M1	JOBTYPES=50 M2	JOBTYPES=50 M3
5	(1)	0.018	0.018	2	0.031	0.025	4	0.021	0.015	2
	(2)	0.000	0.000	10	0.009	0.002	6	0.006	0.000	8
	(3)	0.000	0.000	10	0.009	0.002	8	0.007	0.001	6
	(4)	0.000	0.000	10	0.009	0.002	8	0.007	0.001	6
	(5)	0.000	0.000	8	0.010	0.003	8	0.006	0.000	10
	(6)	0.333	0.333	0	0.458	0.451	0	0.361	0.355	0
10	(1)	0.164	0.155	0	0.154	0.151	0	0.135	0.111	0
	(2)	0.017	0.008	2	0.006	0.003	6	0.023	0.000	10
	(3)	0.020	0.011	2	0.013	0.010	2	0.027	0.003	4
	(4)	0.018	0.009	4	0.013	0.010	2	0.027	0.003	4
	(5)	0.016	0.007	8	0.007	0.003	6	0.047	0.024	6
	(6)	0.416	0.407	0	0.421	0.418	0	0.378	0.354	0
15	(1)	0.181	0.164	0	0.253	0.205	0	0.237	0.179	
	(2)	0.025	0.007	4	0.055	0.007	6	0.069	0.012	4
	(3)	0.024	0.006	4	0.065	0.017	2	0.071	0.014	4
	(4)	0.024	0.006	4	0.066	0.018	2	0.071	0.014	6
	(5)	0.022	0.004	6	0.109	0.061	2	0.137	0.079	2
	(6)	0.320	0.302	0	0.374	0.327	0	0.382	0.324	0

TABLE 3.9 :: FOR R=1.6,T=0.1 (LARGE RANGE, LOW TARDINESS)

M1: Normalised Average Weighted Tardiness
M2: Normalised Average Deviation From The Best
M3: Number Of Times Best Out Of 10
* : Minimum Value Of Normalised Average Weighted Tardiness
+ : Minimum Value Of Normalised Average Deviation From The Best

EFFECT OF RANGE AND TARDINESS (EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	TARDINESS=0.9 M2	TARDINESS=0.9 M3	TARDINESS=0.5 M1	TARDINESS=0.5 M2	TARDINESS=0.5 M3	TARDINESS=0.1 M1	TARDINESS=0.1 M2
	(1)	2.059	0.031	6	0.540	0.030	6	0.024	0.023
	(2)	2.188	0.160	4	0.567	0.057	2	0.001	0.000
	(3)	2.235	0.207	4	0.566	0.055	4	0.002	0.001
0.6	(4)	2.233	0.205	4	0.579	0.068	2	0.002	0.001
	(5)	3.296	1.268	0	0.946	0.436	0	0.002	0.001
	(6)	2.358	0.330	0	0.642	0.132	0	0.072	0.071
	(1)	2.026	0.029	4	0.558	0.092	2	0.013	0.013
	(2)	2.130	0.133	6	0.480	0.015	6	0.000	0.000
	(3)	2.137	0.140	4	0.534	0.069	4	0.000	0.000
1.1	(4)	2.116	0.119	6	0.538	0.072	2	0.000	0.000
	(5)	3.129	1.132	0	0.825	0.359	0	0.000	0.000
	(6)	2.337	0.340	0	0.729	0.264	0	0.169	0.169
	(1)	2.079	0.034	2	0.594	0.181	0	0.018	0.018
	(2)	2.130	0.085	8	0.422	0.009	8	0.000	0.000
	(3)	2.267	0.221	4	0.456	0.042	4	0.000	0.000
	(4)	2.249	0.204	6	0.462	0.048	4	0.000	0.000
1.6	(5)	3.122	1.077	0	0.663	0.249	0	0.000	0.000
	(6)	2.357	0.311	0	0.816	0.403	0	0.333	0.333

TABLE 4.1 :: FOR MACHINES = 5 , JOBTYPES= 7

RANGE	HEURISTIC	TARDINESS=0.9 M1	TARDINESS=0.9 M2	TARDINESS=0.9 M3	TARDINESS=0.5 M1	TARDINESS=0.5 M2	TARDINESS=0.5 M3	TARDINESS=0.1 M1	TARDINESS=0.1 M2
	(1)	2.035	0.047	2	0.639	0.096	2	0.019	0.018
	(2)	2.141	0.153	0	0.618	0.075	4	0.004	0.003
	(3)	2.024	0.036	6	0.595	0.053	4	0.006	0.005
0.6	(4)	2.092	0.105	2	0.618	0.076	0	0.005	0.005
	(5)	2.862	0.874	0	0.962	0.419	0	0.008	0.008
	(6)	2.486	0.499	0	0.897	0.354	0	0.150	0.149
	(1)	2.004	0.055	4	0.505	0.082	4	0.009	0.009
	(2)	2.254	0.306	2	0.559	0.137	0	0.000	0.000
	(3)	1.998	0.049	4	0.457	0.034	6	0.000	0.000
1.1	(4)	2.110	0.161	0	0.551	0.129	0	0.000	0.000
	(5)	2.971	1.022	0	0.648	0.226	0	0.000	0.000
	(6)	2.465	0.516	0	0.921	0.499	0	0.305	0.305
	(1)	1.986	0.045	6	0.480	0.046	2	0.031	0.025
	(2)	2.096	0.155	0	0.523	0.089	2	0.009	0.002
	(3)	2.024	0.083	2	0.473	0.039	6	0.009	0.002
	(4)	2.071	0.130	2	0.623	0.189	0	0.009	0.002
1.6	(5)	2.914	0.973	0	0.885	0.451	0	0.010	0.003
	(6)	2.476	0.535	0	1.003	0.569	0	0.458	0.451

TABLE 4.2 :: FOR MACHINES = 5 , JOBTYPES= 15

EFFECT OF RANGE AND TARDINESS (EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2
	(1)	2.037	0.015	8	0.550	0.005	6	0.015	0.015
	(2)	2.205	0.184	0	0.654	0.109	2	0.000	0.000
	(3)	2.140	0.118	2	0.650	0.104	2	0.013	0.013
0.6	(4)	2.155	0.134	0	0.660	0.115	0	0.014	0.014
	(5)	3.144	1.123	0	1.025	0.480	0	0.001	0.001
	(6)	2.167	0.146	0	0.658	0.113	0	0.100	0.100
	(1)	2.028	0.020	8	0.488	0.013	8	0.000	0.000
	(2)	2.180	0.172	0	0.535	0.059	2	0.000	0.000
	(3)	2.119	0.111	2	0.547	0.072	0	0.000	0.000
1.1	(4)	2.130	0.122	0	0.554	0.078	0	0.000	0.000
	(5)	3.287	1.279	0	0.913	0.437	0	0.000	0.000
	(6)	2.142	0.133	0	0.722	0.246	0	0.178	0.178
	(1)	2.037	0.015	8	0.506	0.043	2	0.021	0.015
	(2)	2.205	0.183	0	0.472	0.008	8	0.006	0.000
	(3)	2.144	0.121	2	0.537	0.073	0	0.007	0.001
	(4)	2.159	0.137	0	0.539	0.075	0	0.007	0.001
1.6	(5)	3.162	1.139	0	0.860	0.397	0	0.006	0.000
	(6)	2.175	0.153	0	0.787	0.324	0	0.361	0.355

TABLE 4.3 :: FOR MACHINES = 5 , JOBTYPES= 50

	(1)	1.830	0.000	10	0.554	0.026	6	0.095	0.090
	(2)	1.980	0.150	0	0.656	0.127	4	0.009	0.005
	(3)	1.994	0.164	0	0.668	0.140	0	0.017	0.012
0.6	(4)	2.043	0.213	0	0.705	0.176	0	0.011	0.006
	(5)	3.143	1.313	0	1.121	0.592	0	0.006	0.001
	(6)	2.378	0.548	0	0.867	0.338	0	0.238	0.233
	(1)	1.815	0.000	10	0.576	0.052	4	0.113	0.113
	(2)	1.980	0.165	0	0.604	0.080	2	0.000	0.000
	(3)	1.963	0.148	0	0.617	0.093	4	0.002	0.002
1.1	(4)	2.010	0.195	0	0.626	0.102	2	0.000	0.000
	(5)	3.111	1.296	0	1.009	0.485	0	0.000	0.000
	(6)	2.359	0.544	0	0.936	0.412	0	0.270	0.270
	(1)	1.829	0.000	10	0.535	0.055	4	0.164	0.155
	(2)	1.992	0.163	0	0.490	0.010	2	0.017	0.008
	(3)	1.974	0.145	0	0.523	0.043	4	0.020	0.011
	(4)	2.027	0.198	0	0.543	0.064	0	0.018	0.009
1.6	(5)	3.031	1.202	0	0.746	0.267	0	0.016	0.007
	(6)	2.381	0.552	0	0.971	0.492	0	0.416	0.407

TABLE 4.4 :: FOR MACHINES = 10 , JOBTYPES= 7

EFFECT OF RANGE AND TARDINESS (EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 5Ø

RANGE	HEURI-STIC	TARDINESS=Ø.9 M1	M2	M3	TARDINESS=Ø.5 M1	M2	M3	TARDINESS=Ø.1 M1	M2
	(1)	1.81Ø	Ø.ØØØ	1Ø	Ø.589	Ø.ØØ5	8	Ø.1Ø4	Ø.Ø79
	(2)	2.Ø23	Ø.213	Ø	Ø.67Ø	Ø.Ø87	Ø	Ø.Ø29	Ø.ØØ4
	(3)	1.977	Ø.167	Ø	Ø.648	Ø.Ø65	2	Ø.Ø31	Ø.ØØ6
Ø.6	(4)	1.975	Ø.165	Ø	Ø.659	Ø.Ø75	Ø	Ø.Ø29	Ø.ØØ4
	(5)	3.175	1.366	Ø	1.153	Ø.57Ø	Ø	Ø.Ø66	Ø.Ø41
	(6)	2.272	Ø.462	Ø	Ø.849	Ø.265	Ø	Ø.213	Ø.188
	(1)	1.794	Ø.ØØØ	1Ø	Ø.575	Ø.Ø11	6	Ø.119	Ø.119
	(2)	2.Ø15	Ø.22Ø	Ø	Ø.615	Ø.Ø51	2	Ø.ØØ2	Ø.ØØ2
	(3)	1.954	Ø.16Ø	Ø	Ø.614	Ø.Ø49	2	Ø.ØØ5	Ø.ØØ5
1.1	(4)	1.947	Ø.153	Ø	Ø.626	Ø.Ø62	Ø	Ø.ØØ5	Ø.ØØ5
	(5)	3.Ø24	1.229	Ø	Ø.97Ø	Ø.4Ø6	Ø	Ø.ØØØ	Ø.ØØØ
	(6)	2.254	Ø.46Ø	Ø	Ø.866	Ø.3Ø1	Ø	Ø.272	Ø.272
	(1)	1.815	Ø.ØØØ	1Ø	Ø.61Ø	Ø.Ø52	4	Ø.154	Ø.151
	(2)	2.Ø58	Ø.242	Ø	Ø.6Ø8	Ø.Ø5Ø	4	Ø.ØØ6	Ø.ØØ3
	(3)	1.974	Ø.159	Ø	Ø.611	Ø.Ø53	2	Ø.Ø13	Ø.Ø1Ø
	(4)	1.971	Ø.156	Ø	Ø.633	Ø.Ø75	Ø	Ø.Ø13	Ø.Ø1Ø
1.6	(5)	2.9Ø9	1.Ø94	Ø	1.Ø63	Ø.5Ø6	Ø	Ø.ØØ7	Ø.ØØ3
	(6)	2.267	Ø.452	Ø	Ø.937	Ø.379	Ø	Ø.421	Ø.418

TABLE 4.5 :: FOR MACHINES = 1Ø, JOBTYPES= 15

	(1)	1.9Ø6	Ø.ØØ5	8	Ø.61Ø	Ø.Ø2Ø	6	Ø.Ø82	Ø.Ø69
	(2)	1.995	Ø.Ø93	2	Ø.654	Ø.Ø64	4	Ø.Ø14	Ø.ØØ2
	(3)	2.ØØØ	Ø.Ø99	2	Ø.697	Ø.1Ø7	Ø	Ø.Ø22	Ø.ØØ9
Ø.6	(4)	2.ØØØ	Ø.Ø99	2	Ø.697	Ø.1Ø7	Ø	Ø.Ø19	Ø.ØØ6
	(5)	2.961	1.Ø59	Ø	1.131	Ø.541	Ø	Ø.Ø26	Ø.Ø14
	(6)	2.264	Ø.363	Ø	Ø.814	Ø.225	Ø	Ø.187	Ø.175
	(1)	1.892	Ø.ØØ3	8	Ø.622	Ø.Ø6Ø	4	Ø.Ø94	Ø.Ø94
	(2)	1.993	Ø.1Ø4	Ø	Ø.614	Ø.Ø51	6	Ø.ØØØ	Ø.ØØØ
	(3)	1.975	Ø.Ø86	2	Ø.588	Ø.Ø26	Ø	Ø.ØØØ	Ø.ØØØ
1.1	(4)	1.975	Ø.Ø86	2	Ø.588	Ø.Ø26	Ø	Ø.ØØØ	Ø.ØØØ
	(5)	2.966	1.Ø77	Ø	1.Ø79	Ø.517	Ø	Ø.ØØØ	Ø.ØØØ
	(6)	2.245	Ø.356	Ø	Ø.866	Ø.3Ø4	Ø	Ø.26Ø	Ø.26Ø
	(1)	1.926	Ø.Ø1Ø	8	Ø.667	Ø.145	Ø	Ø.135	Ø.111
	(2)	2.Ø96	Ø.18Ø	Ø	Ø.534	Ø.Ø11	4	Ø.Ø23	Ø.ØØØ
	(3)	2.Ø11	Ø.Ø94	2	Ø.538	Ø.Ø16	6	Ø.Ø27	Ø.ØØ3
	(4)	2.Ø11	Ø.Ø94	2	Ø.549	Ø.Ø27	4	Ø.Ø27	Ø.ØØ3
1.6	(5)	3.Ø57	1.14Ø	Ø	Ø.978	Ø.456	Ø	Ø.Ø47	Ø.Ø24
	(6)	2.268	Ø.352	Ø	Ø.892	Ø.37Ø	Ø	Ø.378	Ø.354

TABLE 4.6 :: FOR MACHINES = 1Ø, JOBTYPES= 5Ø

EFFECT OF RANGE AND TARDINESS (EQUAL JOB WEIGHTS)
NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	M2	M3	TARDINESS=0.5 M1	M2	M3	TARDINESS=0.1 M1	M2
	(1)	1.957	0.014	8	0.621	0.046	4	0.075	0.075
	(2)	2.106	0.164	0	0.668	0.092	0	0.000	0.000
	(3)	1.997	0.054	0	0.622	0.046	4	0.000	0.000
0.6	(4)	1.997	0.054	0	0.622	0.046	4	0.000	0.000
	(5)	3.352	1.409	0	1.086	0.511	0	0.007	0.007
	(6)	2.181	0.239	2	0.652	0.077	2	0.097	0.097
	(1)	1.944	0.014	8	0.618	0.115	0	0.109	0.109
	(2)	2.089	0.159	0	0.538	0.035	6	0.000	0.000
	(3)	1.984	0.054	0	0.547	0.045	4	0.001	0.001
1.1	(4)	1.984	0.054	0	0.547	0.045	4	0.001	0.001
	(5)	3.267	1.338	0	0.926	0.423	0	0.000	0.000
	(6)	2.162	0.232	2	0.680	0.177	2	0.189	0.189
	(1)	1.977	0.016	6	0.698	0.187	0	0.181	0.164
	(2)	2.190	0.229	0	0.523	0.012	8	0.025	0.007
	(3)	2.005	0.045	2	0.548	0.037	2	0.024	0.006
	(4)	2.005	0.045	2	0.548	0.037	2	0.024	0.006
1.6	(5)	3.342	1.381	0	1.000	0.489	0	0.022	0.004
	(6)	2.179	0.218	2	0.764	0.253	0	0.320	0.302

TABLE 4.7 :: FOR MACHINES = 15, JOBTYPES= 7

	(1)	1.957	0.014	8	0.621	0.046	4	0.075	0.075
	(2)	2.106	0.164	0	0.668	0.092	0	0.000	0.000
	(3)	1.997	0.054	0	0.622	0.046	4	0.000	0.000
0.6	(4)	1.997	0.054	0	0.622	0.046	4	0.000	0.000
	(5)	3.352	1.409	0	1.086	0.511	0	0.007	0.007
	(6)	2.181	0.239	2	0.652	0.077	2	0.097	0.097
	(1)	1.944	0.014	8	0.618	0.115	0	0.109	0.109
	(2)	2.089	0.159	0	0.538	0.035	6	0.000	0.000
	(3)	1.984	0.054	0	0.547	0.045	4	0.001	0.001
1.1	(4)	1.984	0.054	0	0.547	0.045	4	0.001	0.001
	(5)	3.267	1.338	0	0.926	0.423	0	0.000	0.000
	(6)	2.162	0.232	2	0.680	0.177	2	0.189	0.189
	(1)	1.977	0.016	6	0.698	0.187	0	0.181	0.164
	(2)	2.190	0.229	0	0.523	0.012	8	0.025	0.007
	(3)	2.005	0.045	2	0.548	0.037	2	0.024	0.006
	(4)	2.005	0.045	2	0.548	0.037	2	0.024	0.006
1.6	(5)	3.342	1.381	0	1.000	0.489	0	0.022	0.004
	(6)	2.179	0.218	2	0.764	0.253	0	0.320	0.302

TABLE 4.8 :: FOR MACHINES = 15 , JOBTYPES= 15

EFFECT OF RANGE AND TARDINESS (EQUAL JOB WEIGHTS)

NUMBER OF JOBS = 50

RANGE	HEURISTIC	TARDINESS=0.9 M1	TARDINESS=0.9 M2	TARDINESS=0.9 M3	TARDINESS=0.5 M1	TARDINESS=0.5 M2	TARDINESS=0.5 M3	TARDINESS=0.1 M1	TARDINESS=0.1 M2
	(1)	1.699	0.000	10	0.607	0.000	10	0.158	0.076
	(2)	2.001	0.302	0	0.737	0.130	0	0.093	0.011
	(3)	1.820	0.120	0	0.690	0.083	0	0.094	0.012
0.6	(4)	1.820	0.120	0	0.690	0.083	0	0.094	0.012
	(5)	2.921	1.222	0	1.304	0.698	0	0.160	0.077
	(6)	2.068	0.368	0	0.776	0.169	0	0.201	0.118
	(1)	1.693	0.000	10	0.632	0.016	6	0.143	0.141
	(2)	2.050	0.357	0	0.741	0.125	2	0.017	0.016
	(3)	1.805	0.113	0	0.655	0.039	2	0.011	0.010
1.1	(4)	1.805	0.113	0	0.655	0.039	2	0.011	0.010
	(5)	2.982	1.289	0	1.191	0.575	0	0.007	0.005
	(6)	2.050	0.357	0	0.814	0.198	0	0.247	0.246
	(1)	1.706	0.000	10	0.695	0.023	4	0.237	0.179
	(2)	2.161	0.454	0	0.765	0.093	2	0.069	0.012
	(3)	1.826	0.120	0	0.699	0.027	4	0.071	0.014
	(4)	1.824	0.118	0	0.699	0.027	4	0.071	0.014
1.6	(5)	2.960	1.254	0	1.293	0.621	0	0.137	0.079
	(6)	2.067	0.360	0	0.898	0.226	0	0.382	0.324

TABLE 4.9 :: FOR MACHINES = 15 , JOBTYPES= 50

M1: Normalised Average Weighted Tardiness
M2: Normalised Average Deviation From The Best
M3: Number Of Times Best Out Of 10
* : Minimum Value Of Normalised Average Weighted Tardiness
+ : Minimum Value Of Normalised Average Deviation From The Best